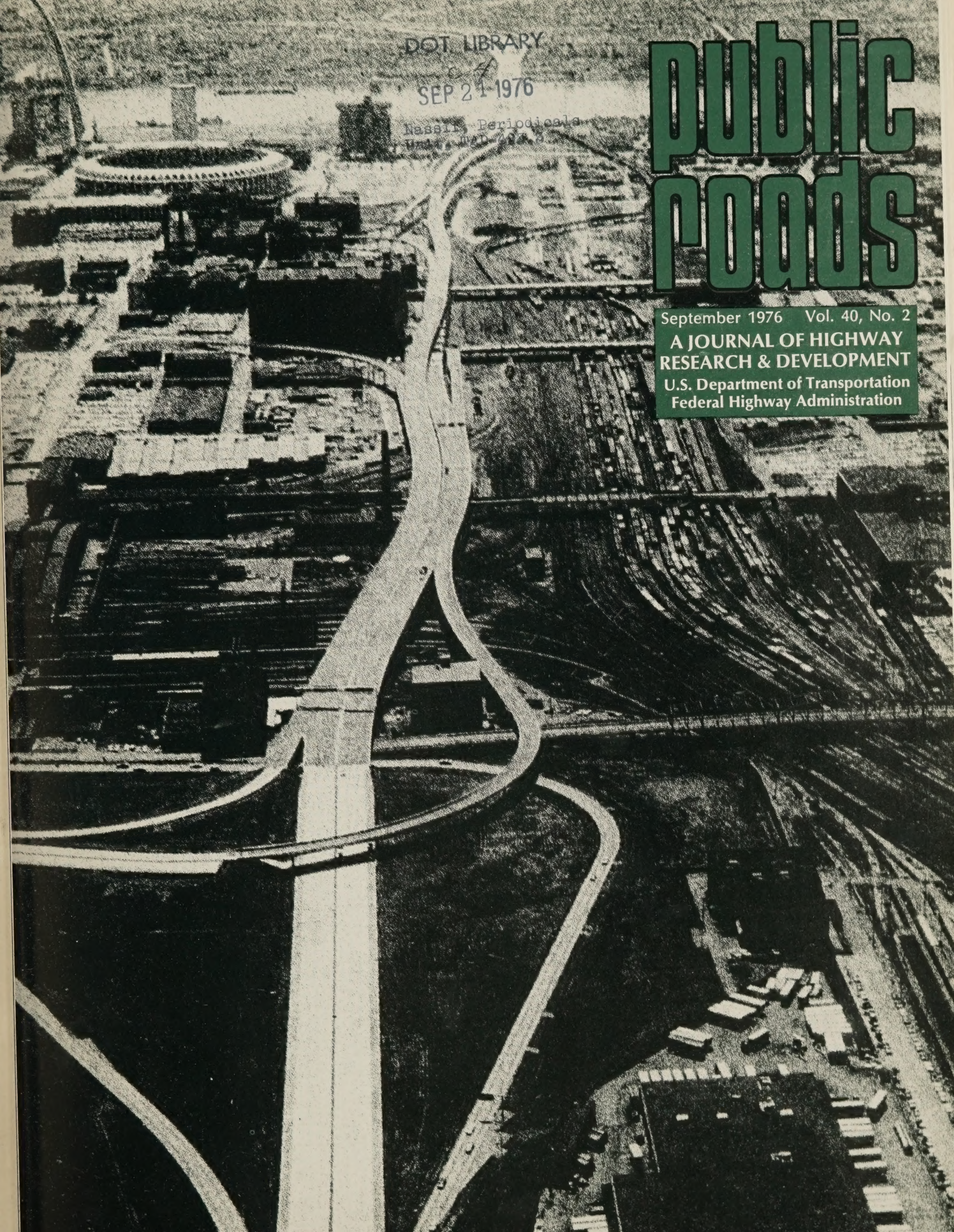


DOT LIBRARY
SEP 21 1976
Nassif, Periodicals
Unit, [illegible]

public roads

September 1976 Vol. 40, No. 2

A JOURNAL OF HIGHWAY
RESEARCH & DEVELOPMENT

U.S. Department of Transportation
Federal Highway Administration

public roads

A JOURNAL OF HIGHWAY
RESEARCH AND DEVELOPMENT

September 1976 Vol. 40/No. 2

FRONT COVER:
Aerial view showing the two-level structure of Route 40 as it threads its way through St. Louis, Mo.

BACK COVER:
1823—The First Macadam Road—From the Highways of History series of paintings by Carl Rakeman.

IN THIS ISSUE

Articles

Instrumented Vehicle Research on Highway Information Systems
by Truman M. Mast, James A. Ballas, and Joseph I. Peters 53

Designing an Instrumented Driver Response System
by Joseph C. Leifer 60

Benefit-Risk Analysis in the Design of Highway Stream Crossings
by Anthony J. Knepp, Ming T. Tseng, and J. Sterling Jones 66

Analysis and Remedies of Freeway Traffic Disturbances
by Samuel C. Tignor 70

Highway Design for Motor Vehicles—A Historical Review
Part 7: The Evolution of Highway Grade Design
by Frederick W. Cron 78

Departments

Our Authors 87

Implementation/User Items 88

New Research in Progress 91

New Publications 69

U.S. Department of Transportation
William T. Coleman, Jr., *Secretary*

Federal Highway Administration
Norbert T. Tiemann, *Administrator*

U.S. Department of Transportation
Federal Highway Administration
Washington, D.C. 20590

Public Roads is published quarterly by the Offices of Research and Development

Gerald D. Love, *Associate Administrator*

Editorial Staff

Technical Editors
C. F. Scheffey, R. C. Leathers

Editor
Stan Metalitz

Assistant Editors
Judith Ladd, Debbie DeBoer

Advisory Board
J. W. Hess, R. F. Varney,
D. Barry Nunemaker,
C. L. Shufflebarger, R. J. Betsold

Managing Editor
C. L. Potter

NOTICE

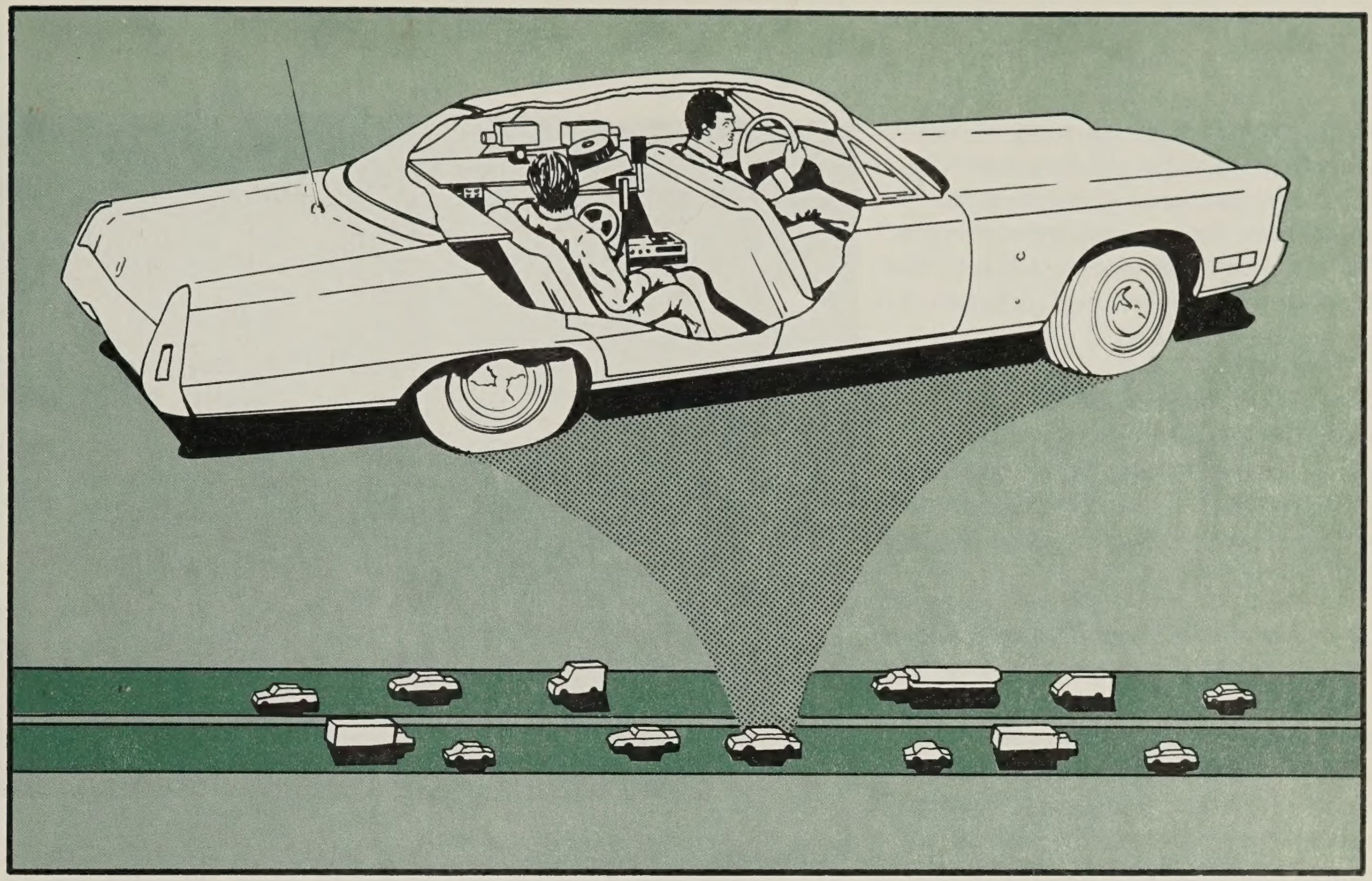
The United States Government does not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of an article.

Address changes (send both old and new), requests for removal, and inquiries concerning the *FREE* mailing list should be directed to:
Public Roads Magazine, HDV–14
Federal Highway Administration
Washington, D.C. 20590

Public Roads, A Journal of Highway Research and Development, is sold by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402, at $7.60 per year ($1.90 additional for foreign mailing) or $1.90 per single copy. Subscriptions are available for 1-year periods. Free distribution is limited to public officials actually engaged in planning or constructing highways and to instructors of highway engineering. There are no vacancies in the free list at present.

The Secretary of Transportation has determined that the publication of this periodical is necessary in the transaction of the public business required by law of this Department. Use of funds for printing this periodical has been approved by the Director of the Office of Management and Budget through March 31, 1981.

Contents of this publication may be reprinted. Mention of source is requested.



nstrumented Vehicle Research on Highway Information Systems

by Truman M. Mast,
James A. Ballas, and Joseph I. Peters

he design of motorist information isplays for the highway transportaon system continues to be a problem or highway engineers. This article escribes a new methodological pproach for the study of highway gning. The technique is called the n-vehicle Sign Simulation (ISS) method and was developed by the Office of Research, Federal Highway dministration. The ISS method equires an instrumented automobile o measure motorists' responses to xperimental signs presented on a creen inside the vehicle. With the SS method, subjects are tested while riving on highways open to normal raffic operations. Heretofore, signing esearchers have had a choice beveen artificial laboratory conditions r poorly controlled field environments for studying new information systems. The ISS method bridges the gap between these two approaches by providing the rigorous experimental control typical of the laboratory and the realism of actual driving.

This article discusses the uses of the ISS method in the context of instrumented vehicle research. The technical aspects of the vehicle's design are described in the article, "Designing an Instrumented Driver Response System," by Joseph C. Leifer which begins on page 60.

Introduction

Instrumented vehicle studies of motorist information systems can vary considerably in methodological approach. The technique developed and used by researchers in the Federal Highway Administration (FHWA) is called the In-vehicle Sign Simulation (ISS) method. With this method experimental information displays are presented to the driver inside an instrumented vehicle as he or she travels to destinations on highways open to normal operations. The instrumented vehicle currently being used in human factors research on highway information systems is described in an article beginning on page 60.

The ISS method was first used in 1972 to develop and evaluate diagrammatic guide signing. (*1*)[1] In the diagrammatic signing studies, slides of the experimental signs were projected onto a small screen positioned on the upper right portion of the windshield on the driver's side (fig. 1). The signs were presented in advance of several test interchanges along a predetermined test route. The signs were designed and presented so that they correlated with actual roadway geometrics, but the place names and route numbers were fictitious. Accordingly, the drivers tested in the studies were instructed to search out fictitious destinations and to ignore the information on the real guide signs.

---

[1] Italic numbers in parentheses identify the references on page 59.

Currently the ISS method is being used to study the influence of certain variable message highway guide signs on the driver's ability to process and interpret directional information. A route diversion signing experiment has been completed which dealt with visual, real-time information display variables. (2) The ISS method can also be used in human factors studies of auditory message variables. A second experiment now in progress examines auditory messages used for route diversion purposes. Other work has been done on route diversion using an in-vehicle presentation of auditory messages. (*3*)

The ISS method is a powerful new research tool for the highway engineer. It offers the sign researcher both the experimental control of the laboratory and the realism of actual driving conditions.

The ISS method has several important advantages:

- Rigorous experimental control can be exercised.
- Large numbers and types of display variables can be efficiently and economically researched.
- Subjective measures using questionnaires and direct questioning by the experimenter can be effectively combined with objective measures of information processing and driving performance.
- Novel and innovative displays can be studied.
- Subtle differences between display variables can be exaggerated for research purposes using various degradation procedures.
- Psychophysiological variables can be studied in relationship with objective and subjective measures.
- The driver's eye movements can be recorded and studied in relation to psychophysiological, objective, and subjective measures.[2]

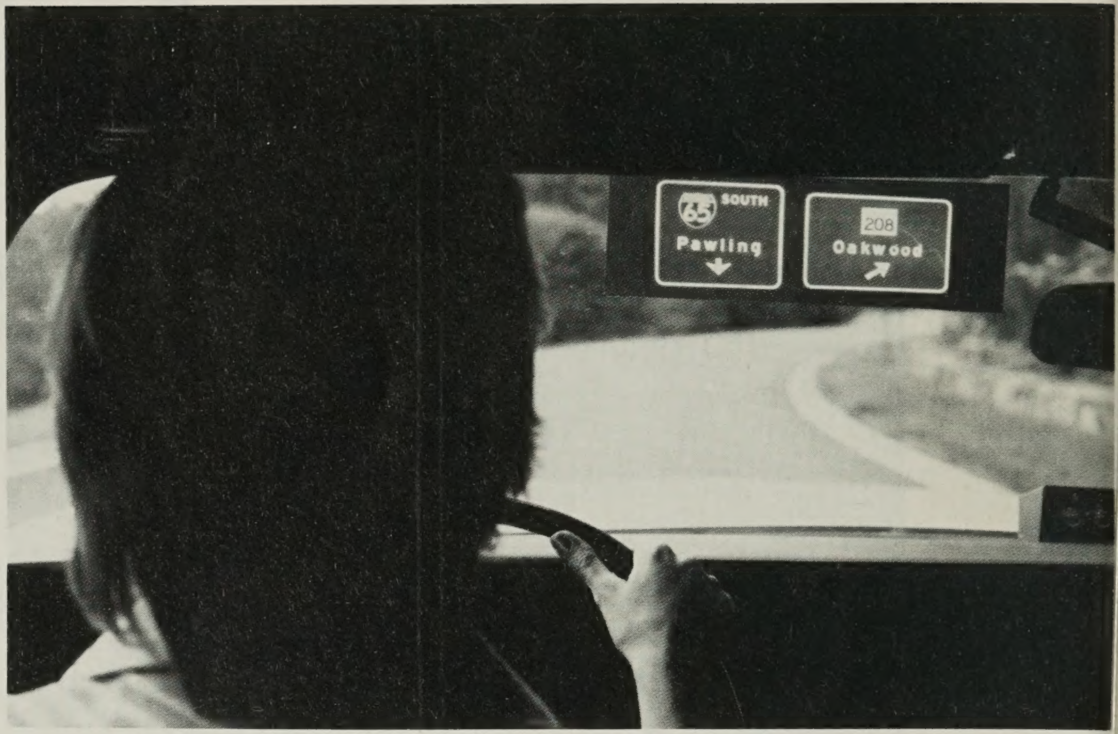


Figure 1.—Driver's view of the in-vehicle display.

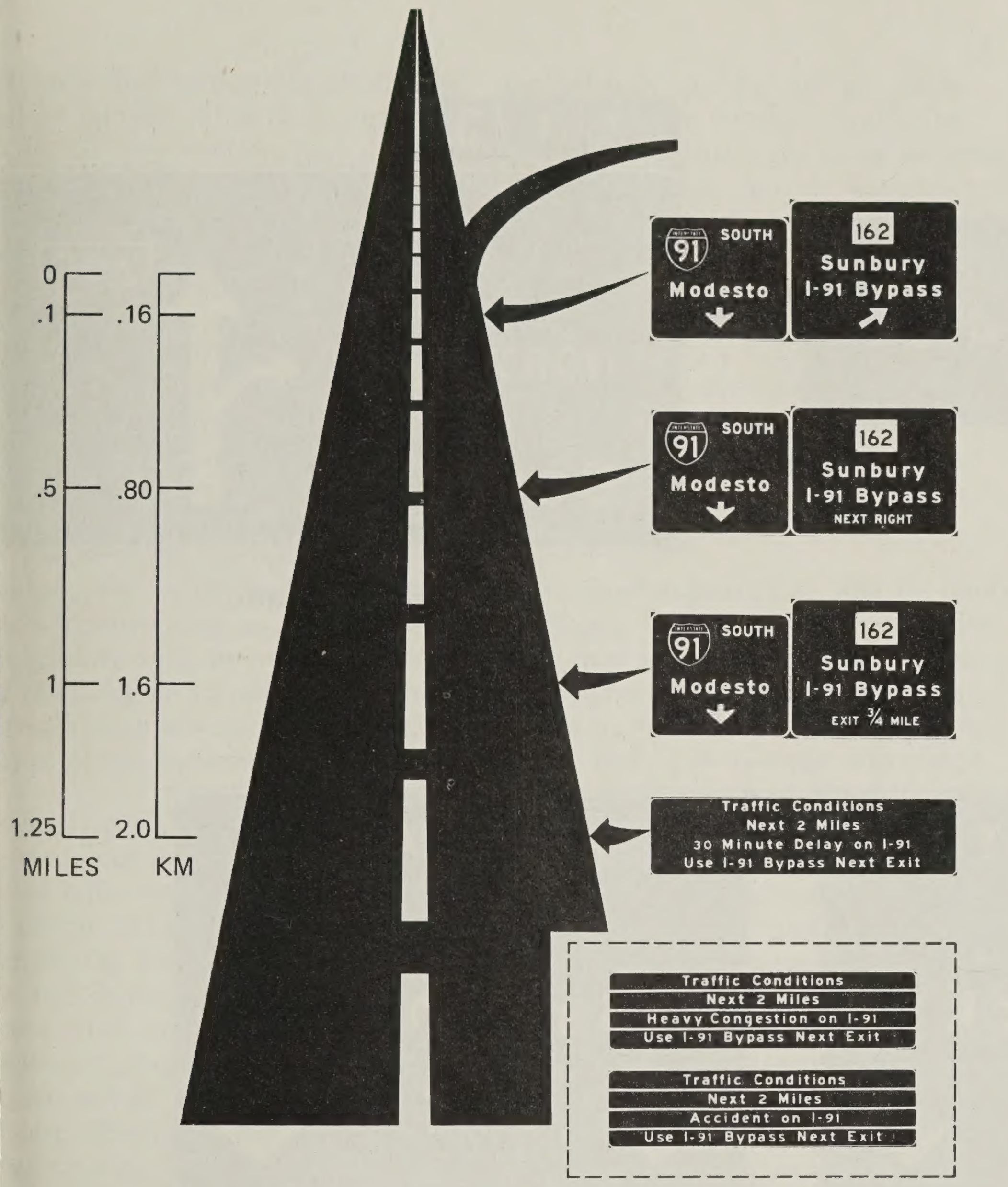
The following are some disadvantages of the ISS method:

- Small sample sizes must be used because drivers must be individually tested. A sample size of 100 subjects approaches the practical upper limit for a given study.
- Aged drivers should not be tested with the ISS method because they have problems adjusting visually to the in-vehicle displays and adapting to novel testing situations.
- The equipment is expensive and fairly complex and the research tean must possess specialized skills.

No one methodological approach is sufficient for studying motorist information systems. Large-scale research in highway signing is best conducted using a combination of methodologie —including laboratory, instrumente vehicle, and on-road field evaluation (*4*) The laboratory offers the best means for initial screening of man kinds of display variables, and on-road field evaluations should be used to make a final assessment of selected information systems. The I method offers the researcher a ste between laboratory research and field evaluations—it can best be us to refine and further develop can date displays produced in the laboratory.

---

[2] Instrumentation for measuring psychophysiological variables and eye movements has not yet been installed in the existing instrumented vehicle.



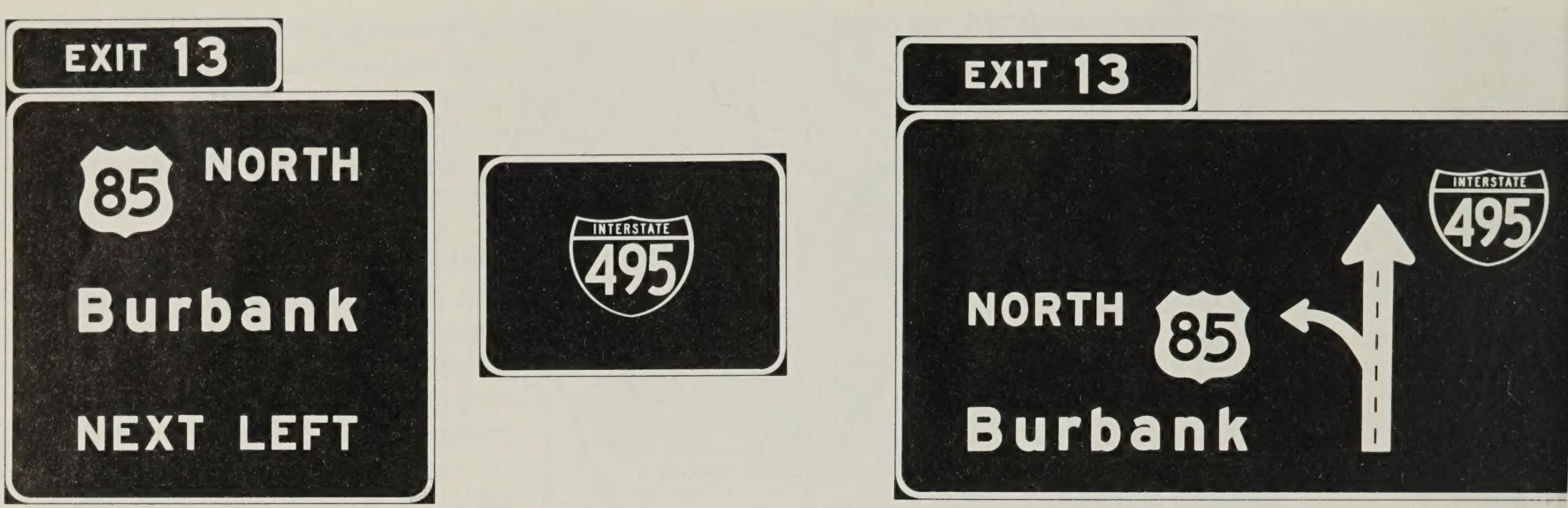
igure 2.—Typical signing presented prior to an exit. Signs in offset were used with other roups of drivers.

esearch Applications

he wide variety of research applica- ons and questions that can be ddressed with the ISS method estab- shes it as a vital phase in a motorist nformation research program. A articular use of the ISS method is in ne area of changeable message signs. ecause of the recent development f changeable message signs, the affic engineer has few technical uidelines to aid him in implementing these signs. In freeway situations where changeable message signs can be used to inform motorists of incidents ahead and to advise them of alternate routes, the traffic engineer should know what type of information would most effectively aid a motorist in choosing a route. The engineer needs to know how far in advance of the decision point each sign should be placed, how many signs are needed to effectively inform drivers of the situation, and what information should come first. By designing test signs in the form of 35 mm slides for in-vehicle use, an experimenter can put virtually anything on each sign. Moreover he or she can easily manipulate the number of signs a driver will see and the location in which they will be seen. For example, figure 2 shows the series of experimental signs used in a recent study. (2)

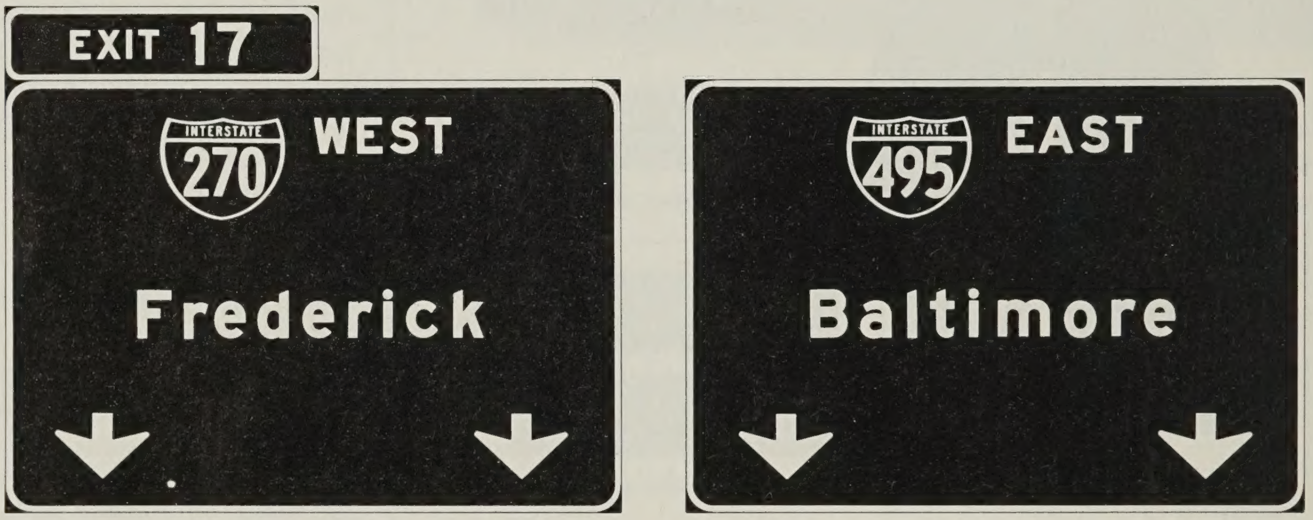
Another application of the ISS method is in the evaluation of new types of signs. Sign hardware technology is continually being advanced particularly in the area of changeable message signs. In response to the research needs generated by recent technical developments, researchers can use the ISS method to economically evaluate drivers' perceptions of different types of displays such as bulb matrix, rotary drum, and standard, fixed message signs. Certain types of signs may be suitable for some functions but inappropriate for others. There are three basic sign functions: regulation (stop signs and speed limit signs); warning (railroad crossing and narrow bridge signs); and guidance (route number and destination signs). (5) Based on driver response it may be that bulb matrix signs are more appropriate for warning than for guidance functions. By varying these functions, an experimenter can assess the impact of each on driver decisionmaking and information processing.

In addition to presenting test signs to the driver, an experimenter can present simulated radio messages as well. By prerecording the messages on tape, the experimenter can cue an in-vehicle tape recorder to play a selected message over the car radio speaker. In this manner, such message variables as content, placement, and function, which can be studied in the context of visual signs, can also be studied in the context of radio

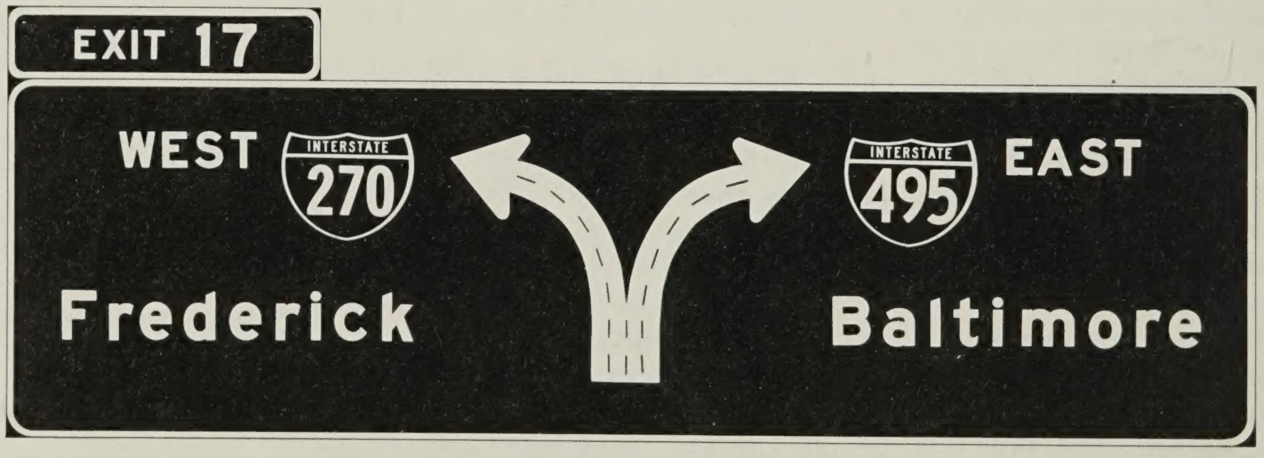


Conventional Diagrammatic

LEFT EXIT



Conventional



Diagrammatic

MAJOR FORK

Figure 3.—Examples of conventional and diagrammatic signs that were evaluated using the ISS technique.

essages. The instrumented vehicle ed in current research is equipped provide any combination of sign d radio messages in any sequence that a researcher can determine e optimum usage of both in a ghway information system.

ther variables which are specific to e visual or the auditory mode can so be studied. For example, merous factors contributing to n legibility such as contrast, color- g, and letter style and size can all systematically manipulated by the perimenter. In the auditory mode, tors contributing to message elligibility such as voice loudness d pitch, signal to noise ratio, and nguage style are also under the ntrol of the experimenter.

search using an instrumented hicle is not limited to the study of n or radio systems. To determine e effects of pretrip planning, for ample, an experimenter can eval- te the driving performance of vers who were allowed reference a map in relation to those who did t use a map. The experimenter also determine the benefits of nap or a navigator to a driver who trying to reach an unfamiliar stination.

manipulating several variables at ce, the experimenter can observe ults which might differ consider- ly from those obtained when iables are evaluated independently. is approach was used in a study ich determined that diagrammatic ide signs were superior to con- ntional signs only when used to dicate left exits or major forks in the d (fig. 3). (6) Had the experimenter looked only at right exit situations, he might have wrongly concluded that conventional signs were superior to diagrammatic signs in all guidance situations. Similarly, by simultaneously considering message modality and message function, an experimenter might find that auditory messages are superior to visual signs only when they serve to warn drivers of hazards ahead, and that visual signs are superior to audio messages in situations requiring route guidance or movement regulation.

In evaluating particular sign or radio messages, the experimenter must be sure that any difference in driving behavior or message reading times is due to message differences and not to the way each message was tested. If college students are used to test one message and businessmen to test another, any difference in reading times might be totally due to the age differences of the groups. Consequently, the experimenter must be sure to balance the test groups on variables such as driver's age, sex, and driving experience. Instructions given to the driver can also affect performance to a significant degree and must therefore be controlled by the experimenter.

Research Measures

The instrumented vehicle approach enables the researcher to use a wide variety of objective and subjective measures to assess the effects of different types of messages and different driving situations. These objective and subjective measures provide data to evaluate alternative solutions to the issues previously discussed.

Objective measures

The objective measures include data on the driver's cognitive processing and vehicular control. A cognitive measure that has been used very successfully is Information Interpretation Time (IIT). This is the amount of time the driver uses to read and interpret a particular sign or radio message. (*1*) The IIT measure has been used to compare diagrammatic and conventional signing and to compare different types of information on simulated rotating drum signs which advise the driver of the traffic situation ahead. (*1, 2*) For example, research has shown that a driver can read and interpret signs giving the level of congestion ahead faster than signs giving the time delay or a description of an incident ahead. The signs tested are shown in figure 2.

The driver's route choices provide an objective measure of decisionmaking. In a study of advisory signs, route choice was a critical measure since it indicated that the choice to divert and take an alternate route is affected not only by the severity of the situation described in the advisory information, but also by the type of information. (*2*) In research now underway the effect of information which describes the situation on the road ahead is compared to information which offers the driver an alternate route.

The vehicular performance measures which are described in the article beginning on page 60 are used to evaluate the impact of signing and radio messages on the driver's control of the vehicle. Through software programing, a profile of the vehicular

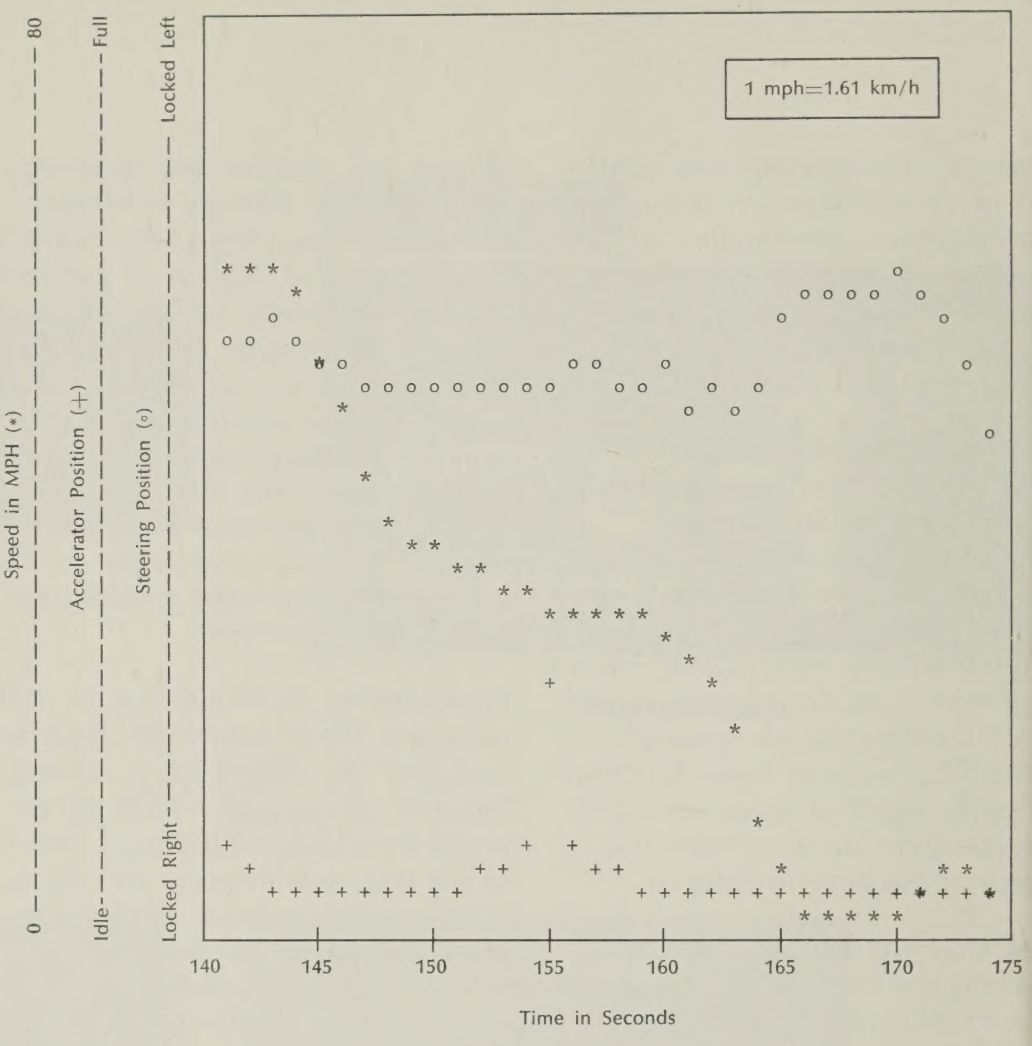


Figure 4.—Profile of vehicle performance during an exit from a parkway.

performance over a section of the test route can be plotted and analyzed. Figure 4 shows such a plot and includes the speed of the vehicle, the accelerator pedal positions, and the steering wheel positions within each sampling period of 1 second. Experimental events such as the presentation (by the experimenter) and the termination (by the subject) of sign displays and radio messages can also be indicated. Analysis of these profiles provides insight into the dynamic behavior of the driver, as influenced by the experimental situation.

Additional objective information on the driver's behavior is obtained by analyzing time-lapse film of the roadway taken from the vehicle during the experiment. Lane changes and erratic maneuvers can be tallied and used to evaluate experimental signing. For example, the proportion of correct lane changes made by drivers while negotiating complex interchanges was a sensitive measure of the relative effectiveness of diagrammatic versus conventional guide signs. (*1*) In particular, correct preparatory lane changes, along with other measures, indicated that diagrammatic guide signs provide substantial benefit at interchanges with left exits.

The instrumented vehicle provides the capability to obtain objective data on two other important areas of driver behavior: memory and psychophysiology. An instrumented vehicle has been used in other research to evaluate the amount of information in a radio message that drivers can remember and use. (*3*) Radio messages with different amounts of information were presented and the results analyzed to determine the amount of information that the driver could correctly recall or recognize.

Psychophysiological instrumentation is being planned for the instrumented vehicle for use in future experiments. Heart rate and respiration will be recorded and used to analyze the stress and workload of the driver during test runs. These psychophysiological data will be correlated with other objective data and with the experimental events that occur. This measurement capability will provide an important dimension to the evaluation of novel communication and information transfer techniques.

Subjective measures

The subjective measures that are use with the ISS method are generally verbal responses to questions asked during a road test. In experiments where route choices are required, drivers are asked why they made specific decisions. Analysis of the recorded responses provides informa tion on the decision processes the driver uses. One experiment showe that a sign which provided a description of an incident on the road ahead (for example, *Truck Overturned*) prompted drivers to reflect on their past experiences wi such incidents. (*2*) Drivers who ha previously experienced delays with such an incident often decided to take the alternate route. On the other hand, drivers who had experienced little or no delay with such incidents would tend to continue on their main route.

A route choice is an all-or-none decision, but a driver's evaluation of the alternatives is not discrete. In order to assess a driver's evaluation of the alternatives on a finer scale, drivers are asked how confident they are about their decisions. These subjective confidence ratings provide data to distinguish between a clear or a confused decision.

The driver's subjective opinions and preferences about signing are typically obtained in experiments with the ISS method. These data provide comparisons with other research studies and provide background information on the persons recruited as drivers. General comments are also encouraged since they provide the researcher with new viewpoints and often provide insights into the cognitive or situational factors that combine to produce the results.

Summary and Conclusions

The capabilities and limitations of a new research tool for studying highway information systems have been presented. The new technique is called the In-vehicle Sign Simulation ISS) method and uses a specially equipped automobile. It has primarily been used to study the effects of sign message variables on driver nformation processing and decisionmaking. The ISS technique offers the investigator rigorous experimental control, economy, and efficiency similar to that found in laboratory studies. In addition, it provides the realism of driving under real-world highway conditions since the driver can be systematically studied as he or she performs under the demands and hazards of actual highway travel.

The research variables that can be studied with the ISS method are: display types (variable versus fixed message), message function (guide versus regulatory), message content (graphic versus printed legend), message format, message placement, message redundancy, message modality (auditory versus visual), message legibility and intelligibility, pre-trip planning, and navigational aids. The interactions of these variables with highway geometrics, other highway design features, and driver variables such as route familiarity and driving experience can also be studied. The measures used to study these variables are: Information Interpretation Time, route choice decisions, vehicular control (speed and steering control), performance on memory tasks, and psychophysiological and subjective responses.

A glimpse into the future suggests that user information systems will continue to be important to the successful operation of surface transportation systems. We are approaching a new era that will be characterized by many alternate transportation modes for moving people and goods in American cities. With this trend there will most assuredly be an increase in the problems associated with user information needs. The motorist will no longer have the city virtually to himself but will have to compete for information channels with other transportation modes. Information transmission will have to be extremely efficient to avoid modal conflicts and facilitate intermodal transfer operations. The development of new research tools such as the ISS method must continue so that we can successfully meet these challenges of the future.

REFERENCES

(1) T. M. Mast, J. B. Chernisky, and F. A. Hooper, "Diagrammatic Guide Signs for Use on Controlled Access Highways. Volume II—Laboratory, Instrumented Vehicle, and State Traffic Studies," Report No. FHWA–RD–73–22, *Federal Highway Administration,* Washington, D.C., December 1972.

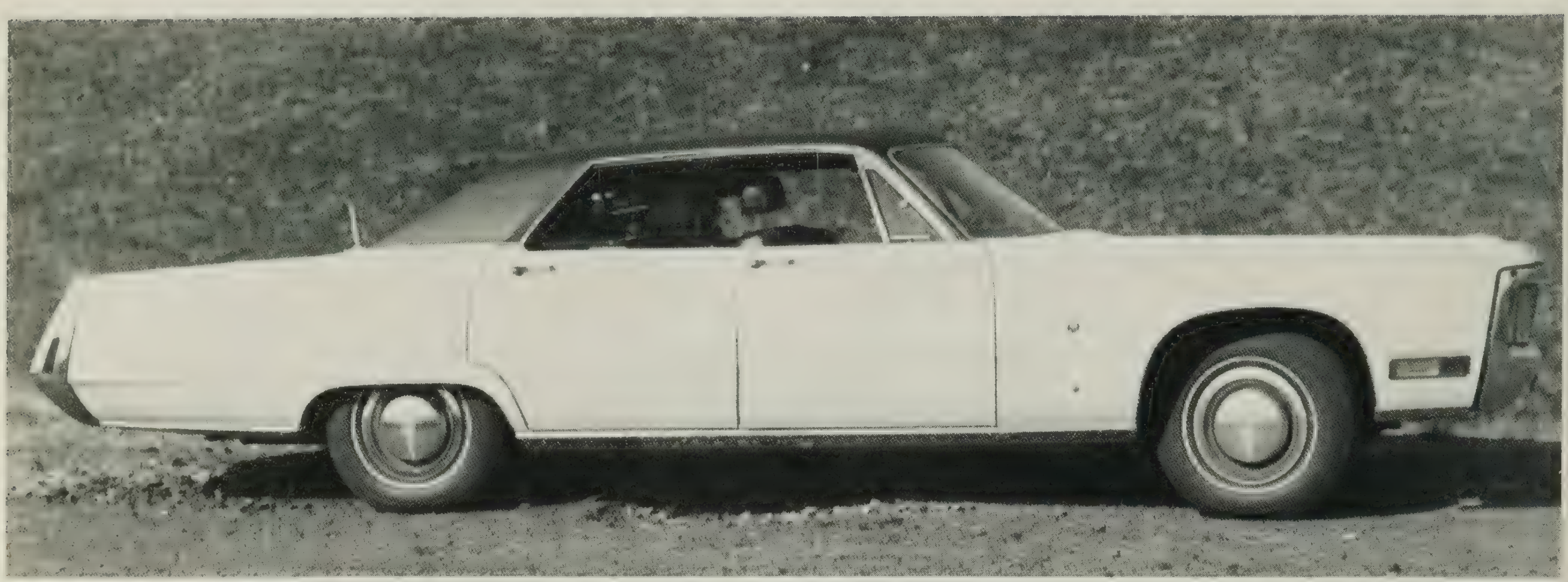
(2) T. M. Mast and J. A. Ballas, "Diversionary Signing Content and Driver Behavior." Paper presented at the 55th annual meeting of the Transportation Research Board, Washington, D.C., January 1976.

(3) F. P. Gatling, "Auditory Message Studies for Route Diversion," Report No. FHWA–RD–75–73, *Federal Highway Administration,* Washington, D.C., June 1975.

(4) T. M. Mast, "Alternative Techniques for Testing Highway Information Systems." Paper No. 74–1303 presented at the American Institute of Aeronautics and Astronautics Life Sciences and Systems Conference, Arlington, Tex., November 1974.

(5) National Joint Committee on Uniform Traffic Control Devices, "Manual on Uniform Traffic Control Devices for Streets and Highways," *Federal Highway Administration,* Washington, D.C., 1971.

(6) T. M. Mast and G. S. Kolsrud, "Diagrammatic Signs for Use on Controlled Access Highways. Volume I—Recommendations for Diagrammatic Guide Signs," Report No. FHWA–RD–73–21, *Federal Highway Administration,* Washington, D.C., December 1972.



Instrumented vehicle—general view.

Designing an Instrumented Driver Response System

by Joseph C. Leifer

In 1973, the Engineering Services Division of the Office of Development, Federal Highway Administration (FHWA), was requested to design and install a vehicle driver response instrumentation system. The purpose of the system was to measure response to audio and visual stimuli. Although detailed functional performance specifications were given, the means for fulfilling them were left to the Electronic Instrumentation Group of the Engineering Services Division. This article presents an overview of nontechnical and technical considerations for designing such a system as well as element-by-element descriptions of the system's operation and detailed design considerations. Experimentation being conducted using this vehicle is described in an article by Mast, Ballas, and Peters beginning on page 53.

Introduction

On July 2, 1973, the Traffic Systems Division of the Office of Research at the Federal Highway Administration (FHWA) requested the Engineering Services Division of the FHWA Office of Development to design and install an instrumentation system in a 1970 Chrysler Imperial automobile. The purpose of the instrumentation was to investigate driver response to audio and visual stimuli.

The Traffic Systems Division detailed the specifications for the system's functional performance and the design and installation of the system were left to the Electronic Instrumentation Group of the Engineering Services Division.

Nontechnical Design Considerations

An instrumented vehicle is one of the most useful and cost-effective tools that can be used for human factors research in driver behavior. The time and effort required to extensively instrument a vehicle, however, brings forth a number of nontechnical considerations that will affect the system plan.

Perhaps the most obvious consideration is maintaining a close liaison between those who will be using the vehicle and those designing the instrumentation equipment. The users' needs and preferences should be taken into account when making design decisions. Trade-offs should be made to the extent possible within technical limitations. However, sophistication and refinement may have to be compromised to meet a completion date determined by contractual commitments.

An instrumented vehicle will be used by drivers who are unfamiliar with its handling characteristics. Since they will be driving in traffic while being given audio and visual stimuli, safety becomes an important consideration. Equipment mounts designed to withstand survivable crashes and an auxiliary rear seat brake pedal for the experimenter should be provided.

A realistic driving environment can be established within the instrumented vehicle by carefully planning the placement of equipment. This will give the driver a clear field of view and provide weight distribution that will not adversely affect handling.

A blower can be used to ventilate the trunk, which will contain heat-generating equipment as well as explosive-gas-generating auxiliary lead-acid batteries. Where necessary, sounds produced by the instrumentation equipment can be minimized by sound absorbing material. A two-way radio should be in the vehicle so assistance or coordination with another test vehicle can be obtained.

The experimenter and assistants, whose attention is on obtaining data from a test run, will be occupied with such things as orienting the subjects, controlling stimuli, and surveying the current and expected traffic conditions. Therefore, the instrumented vehicle—although complex—must be planned and constructed so that it can be operated with a minimum of concentration beyond that required for normal driving.

The system to be described here is complex and involves two voice recorders, a digital magnetic tape recorder, a 20-column printer, a 35 mm slide projector, and two cameras. Although this requires considerable "pretrip" activity, by following detailed procedures an experimenter can successfully use the equipment without much effort while enroute.

Technical Design Considerations

System configuration

The choice of an analog or a digital instrumentation system for a vehicle depends on many factors:

- Number of channels needed.
- Bandwidth of various channels.
- Precision of needed data.
- Nature of parameters to be measured and types of transducer judged most suitable for the measurements.
- Time available to implement the system.
- Availability of downstream data processing equipment and software.
- Availability of portable analog or digital instrumentation components.
- Extent of processing required.
- Duration (time) of one experimental run or series of runs.
- Total contemplated usage of vehicle.

For the system being discussed, consideration of the above factors resulted in a decision to implement a computer-compatible digital system. The users also determined that they could solve the problem of not knowing the quality of the data collected until the processing was complete by requiring an instantaneous printout of data identical to that recorded on magnetic tape. In this way, the operation of all equipment in the system (other than the magnetic tape recorder), as well as experimental data, could be monitored in real time. Also, diagnosis of tape errors or computer processing problems would be simplified since these results have to duplicate the data produced by the printer.

System requirements

The users of the instrumented vehicle specified that the following parameters be measured and be recorded once per second:

- Vehicle velocity—to a precision of 0.1 mph (0.16 km/h). Range of measurements 0 to 99.9 mph (0 to 159.3 km/h).
- Distance traveled from arbitrary start point—to a precision of 0.01 mile (0.016 km). Range of measurement 0 to 99.9 miles (0 to 159.3 km); manual reset.
- Latency of subject response (time between initiation of a stimulus and subject response)—to a precision of 0.01 second. Range of measurement 0.01 to 79.99 seconds; automatic reset.
- Steering wheel position—in 100 increments from 00 at right lock to 99 at left lock.
- Accelerator position—in 100 increments from 00 at curb idle to 99 at full throttle.
- Steering wheel reversals—all reversals in steering wheel direction of rotation occurring each second. Range 0 to 9.
- Accelerator reversals—all reversals in accelerator pedal direction of movement occurring each second. Range 0 to 9.
- Brake applications—the number of times each second that the brake pedal is applied. Range 0 to 9.
- Event codes—the action of the experimenter in initiating or terminating stimuli, or marking some other event, is encoded and placed on the data tape as is the subject's termination of a stimulus. Four codes used (of the 10 available).
- Time from beginning of an experimental run—implicitly obtained from the crystal-controlled, 1-second interval between readings.

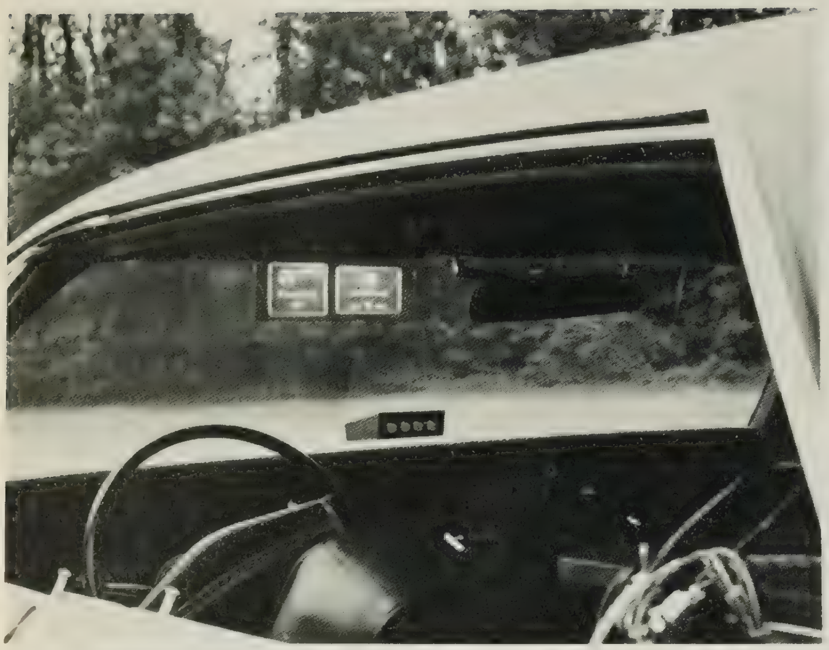


Figure 1.—Subject response lamps on dashboard and projection screen on windshield.

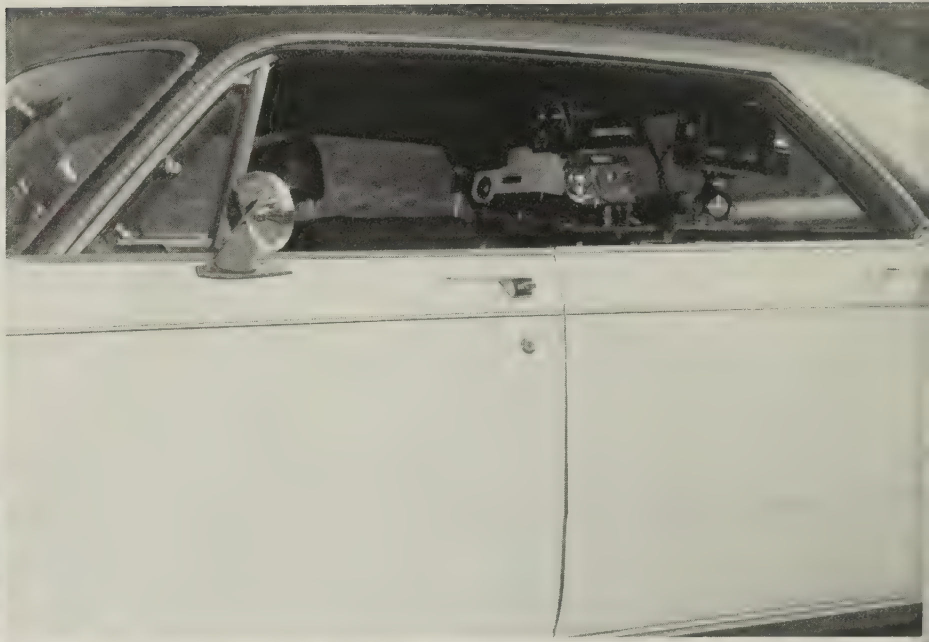


Figure 3.—Slide projector and two cameras (front and rear window views).

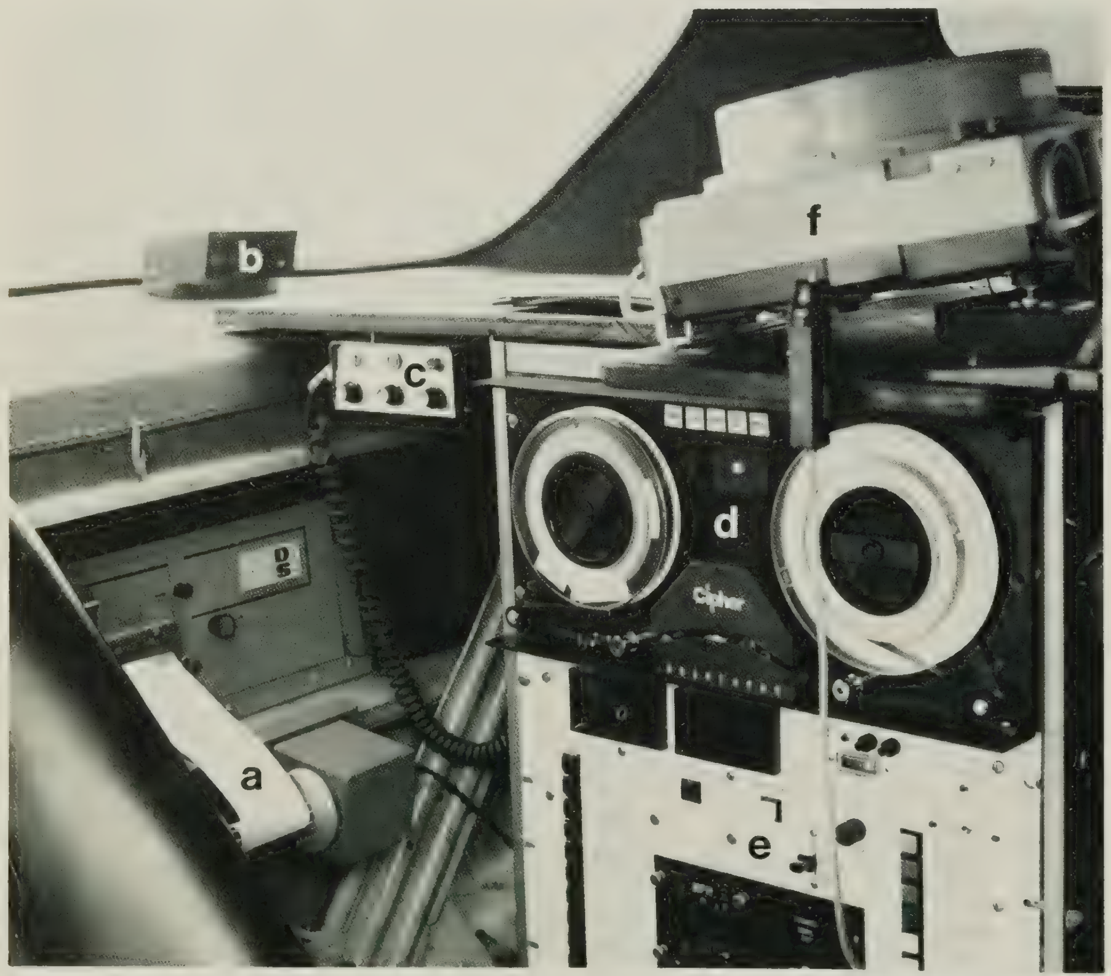


Figure 2.—View into rear seat showing 20- column printer (a), subject response lamps (b), two-way radio (c), magnetic tape recorder (d), control panel (e), and slide projector (f).

System Operation

Visual stimulus

The experimenter presses the appropriate button to present a visual stimulus to the experimental subjec The stimuli are presented by a remote-controlled projector having an 80-slide magazine. The experimenter presents the next slide in the sequence by pressing a visual stimulu button located either on a miniature control box at the end of a flexible cable, or on the control console behind the front seat.

In response, the system sounds an alerting tone for 1.5 seconds, illum nates the proper bulb from each of two sets of four bulbs (figs. 1 and located within view of two, one-frame-per-second cameras position to photograph the view through th front and rear windows of the vehic (fig. 3), and changes the slide in the projector. The slide is viewed on special projection screen located the windshield (fig. 1). Its size, brig ness, and location simulate a highwa sign. Simultaneously, the latency timer is started and a visual event stimulus code is recorded.

Vhen the subject has seen and nderstood the visual stimulus, he or he terminates the stimulus by queezing the horn ring on the teering wheel of the vehicle. This emoves the slide (by changing to a lank), illuminates the subject reponse lamps in camera view, stops he latency counter, electrically unocks the experimenter's control box o that another command may be sued, and writes a subject response ode into the data record.

udio stimulus

udio stimuli are presented to the ubject when the experimenter resses the appropriate button. This nitiates a 1½ second alerting tone, arts the latency timer, illuminates the ppropriate front and rear bulbs, and arts an audio cassette recorder that lays through the vehicle's radio oudspeaker and gives a verbal inruction to the subject. If the subject oes not terminate the instruction, is automatically repeated as many mes as necessary.

/hen the subject terminates the essage by squeezing the horn ring, ne latency counter stops, the front nd rear light bulbs that indicate ubject response illuminate, and the udio output of the recorder is muted the message is not repeated. The pe continues to run, however, ntil the beginning of the next series audio messages. The stimulus ommand buttons are now activated.

ata recording devices

ve different recording instruments e used to allow the experimenter to ecisely review the location, traffic, eather, road conditions, and other ctors existing during the experiment.

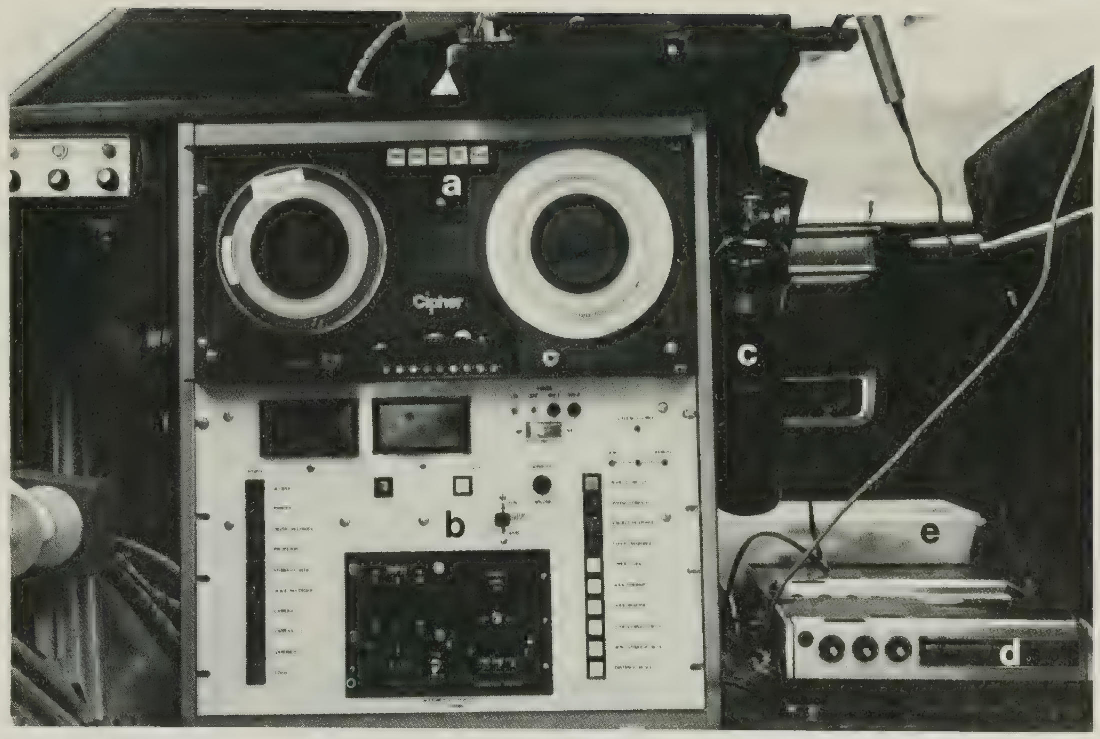


Figure 4.—View with rear seat removed showing digital magnetic tape recorder (a), detail of control panel (b), fire extinguisher (c), two audio recorders (d), and parts storage box (e).

These recording devices include a computer-compatible, 9-channel, reel-to-reel incremental digital magnetic tape recorder (figs. 2 and 4). This records, for later analysis, all the experimental parameters previously described.

Another recording device is a 20-column printer that provides an immediately readable record of the experiment's progress (fig. 2). In this way, proper operation of all equipment and proper recording of all parameters can be ascertained before the run has been completed. The printer operates at a rate of one line per second and contains data that is identical to that placed on the magnetic tape recorder.

In addition to the data recorders is an audio voice recorder. Its function is to record all comments made by the experimenter and the subject. This device provides both a convenient means for the experimenter to comment on any unusual occurrences and also a means for the experimenter to reconstruct a situation under which questionable results were obtained.

Two 16 mm cameras operating at one frame per second are mounted on a table behind the front seat. Their fields of view are adjusted to photograph driving conditions in front of and behind the vehicle, as well as to record the condition of the four stimulus-response indicator lights. The frame advance rate is controlled by a clock generator located in the logic and control equipment so that each frame is keyed to all other data collected during the experimental run.

Detailed Design Considerations

Power

Instrumenting a vehicle almost always involves problems of obtaining reliable, spike-free primary power, usually at both 12 or 24 VDC and 115 VAC, 60 Hz. Transistor technology and integrated circuitry have eased many of these problems by enabling much modern electrical equipment to be small and to consume little power.

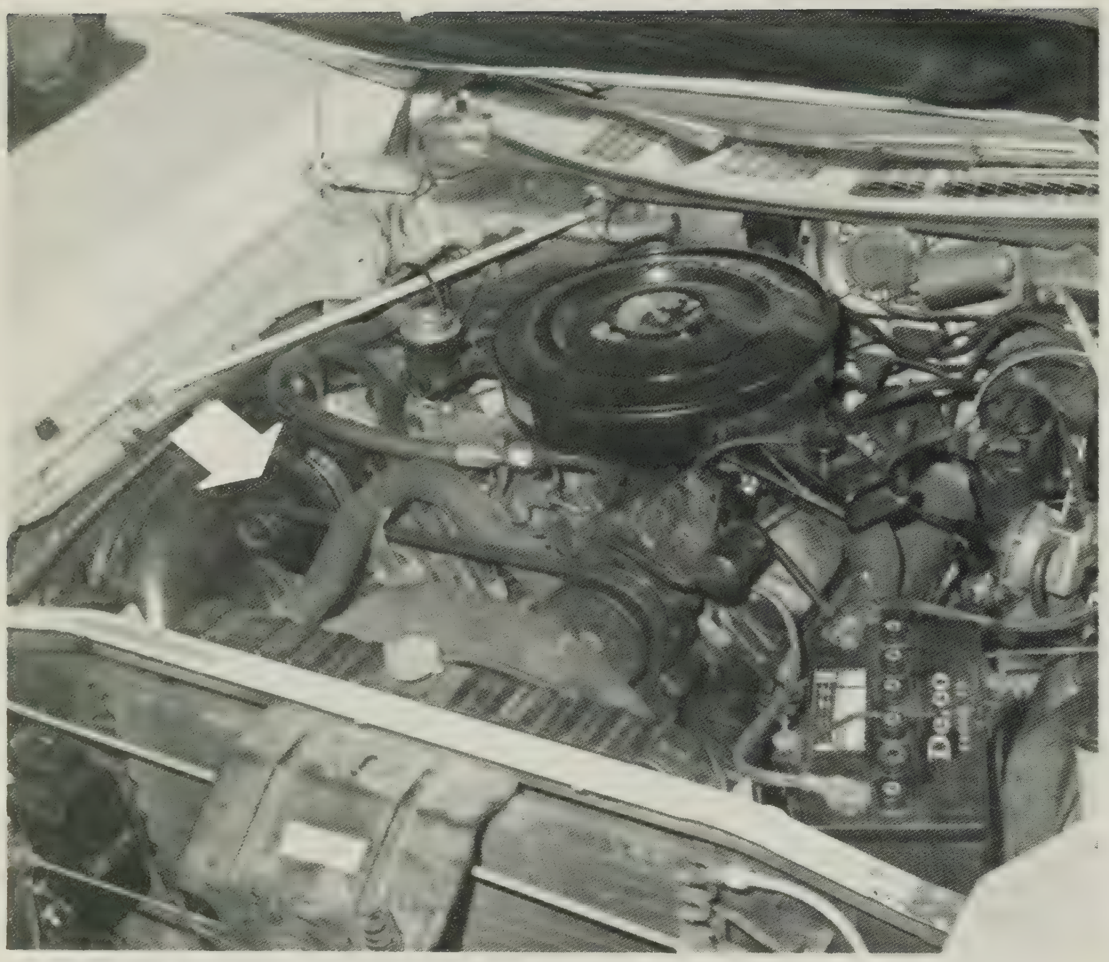


Figure 5.—View of engine compartment showing auxiliary 24-volt 105 ampere alternator.

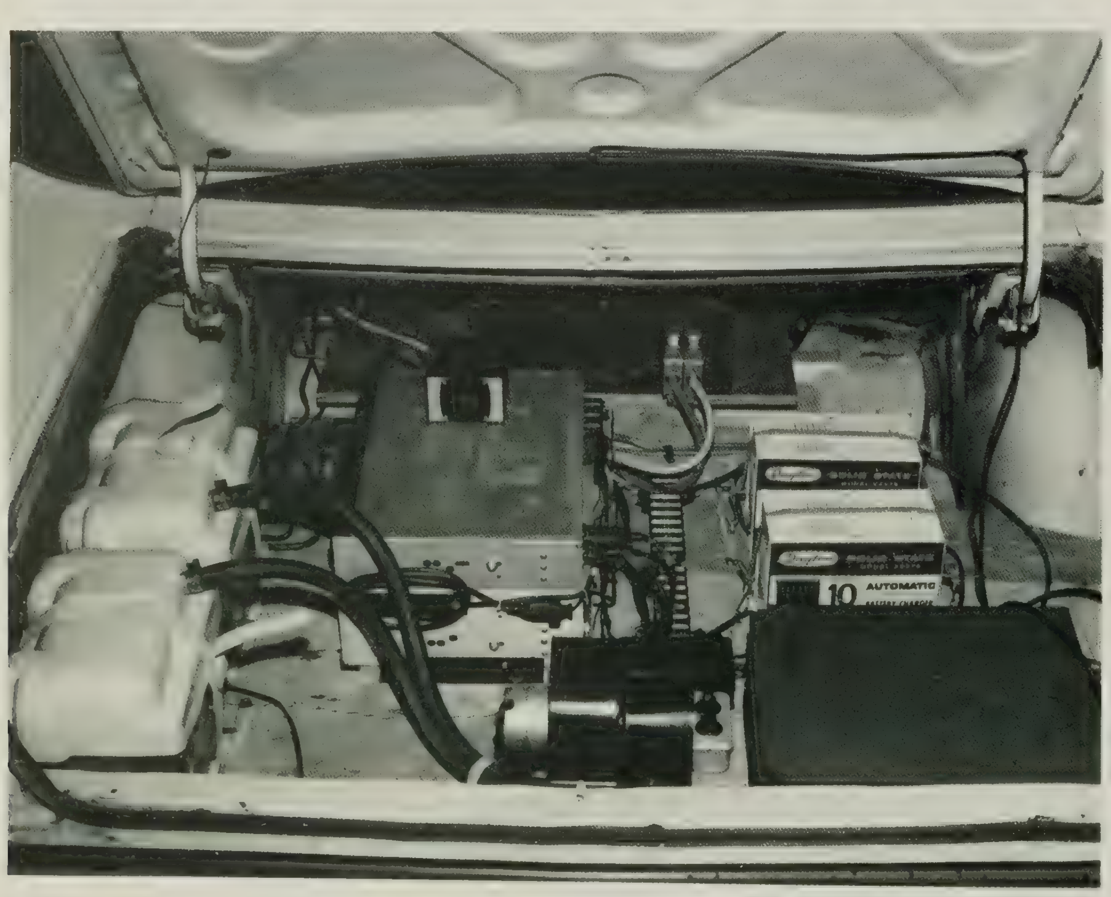


Figure 6.—View of trunk showing two 12-volt batteries (left), exhaust fan (bottom, center), sine-wave inverter (center), two battery chargers (top, right), and two-way radio (bottom, right).

However, certain items of electromechanical equipment such as pape chart recorders, slide projectors, and magnetic tape recorders contain motors and solenoids that require considerable power.

In the vehicle described, the pulse cameras were designed for industri or military use and require 24 VDC. The largest power drain in the vehicl is the slide projector which requires 115 VAC for its motor and slide changing mechanism, and for its projection bulb. Although rather inefficient, this power drain is unavoidable since there is no adequat low-voltage bulb available for this projector.

The line printer and the digital magnetic tape recorder also require generous amounts of good quality AC power. This power is supplied l a static (non-rotating) inverter havin good waveform with satisfactory efficiency and good reliability.

A 1 kW inverter, as used here, ope-ates more efficiently on 24 volts tha on 12 volts DC. Also, since the vehicle's generator would not be ale to handle the entire electrical loa by itself, an additional 24-volt, 105 ampere alternator was fitted into th engine compartment (fig. 5). This unit supplies current to two serie connected 12-volt batteries located in the vehicle's trunk and connecte to the static inverter and the puls cameras (fig. 6).

Power drain in the vehicle can be s great that control is interlocked by a relay through the vehicle's ignitio switch. This is intended to encourage engine operation whenever equ-ment is operated. The control panel permits monitoring of primary power inverter output, and the energizing of each power-consuming element of the instrumentation system.

ectrical grounding system

igh current drains by some of the w voltage equipment made it ecessary to pay special attention to w voltage grounding. Both the -volt and the 24-volt alternator gative terminals were brought out the alternator frames. An effective ngle-point ground was made by nning heavy bus wire from each ernator frame to a nearby chassis int, and from there to power stribution points for the control nel and the inverter. No other con- t with the vehicle's chassis was nde for power return.

nsducers

e speed and distance transducer is ourchased unit attached to the pedometer cable with a "Y" fitting. is unit has an optical disc that oduces a nominal 36,000 pulses per parent mile of travel as determined the speedometer gearing, tire meter, and wheel slip. A thumb- eel-adjusted correction circuit mpensates for tire size and wear in distance reading, but no correc- n is available for the speed readout. tance is determined after dividing transducer pulses by a nominal tor of 360, which gives 100 pulses mile, and these results are played and recorded.

h a transducer providing 36,000 ses per mile, speed is easily ained by counting the number of ses occurring each second and playing this number as speed to nearest 0.1 mph (0.16 km/h). The er-second read and reset pulses this counter are supplied by a rtz crystal in the clock generating uitry.

ncy measurement

ncy of subject response is asured simply by opening the gate to a counter and allowing 100 kHz pulses from the clock to accumulate in it. Subject response closes the gate to the counter, which holds the count until completion of the next printing cycle. The counter is then zeroed in preparation for the next count.

Desired outputs of the latency counter are sampled by the printer and the magnetic tape recorder once each second. The latency time following a stimulus will build at the rate of 1 second per sample to a final peak value. This value is stored at the instant of the subject's response, and the counter is reduced to zero when reset at the next clock time.

Steering wheel and accelerator position

Steering wheel and accelerator position data are generated from a conventional multiturn and a linear potentiometer that are attached, respectively, to the steering wheel shaft and the throttle linkage so that backlash and lost motion are minimized. The potentiometers are energized from regulated, filtered voltage. Their outputs are passed through an operational amplifier signal conditioner that provides a low impedance output and allows for zero and full-scale adjustment. Using this circuit gives complete flexibility in the establishment of a zero-voltage point and scale adjustment to provide a 10-volt maximum signal.

The operational amplifier outputs are fed into two digital panel meters which display transducer position and provide a digital output that is recorded on both the magnetic recorder and the line printer. The position transducer outputs are also fed to circuits that sense when a position voltage is increasing or decreasing, thus detecting changes from one direction to the other (reversals). Each detected change in direction is stored in a counter from which data are recorded each second, after which the counter is reset to zero.

Brake applications

Brake applications are detected by conditioning (low pass filtering and limiting) the voltage appearing on the brake light circuit. This permits each application to be counted, printed out, and erased in a manner similar to that used for steering wheel and accelerator position reversals.

Conclusion

After the equipment was built, it was tested in the electronics laboratory. All faulty components and errors in logic and wiring were corrected. The equipment was then installed in the vehicle along with cameras, transducers, a two-way radio, a 24-volt alternator, a power distribution system, and an exhaust blower.

Difficulties were anticipated in three general areas: (1) supply of primary power, (2) unreliability in the digital magnetic tape recorder, and (3) logic and data errors due to transients produced by the operation of electrical equipment within the vehicle. Fortunately, the only difficulty experienced was transient pickup from such events as opening a door (light switch), or operating the turn signals, the horn, or certain other accessories. However, bypassing this equipment with capacitors and diodes overcame these difficulties.

Along with this debugging, a detailed instruction manual for operating the system was prepared and informal training sessions held for personnel who were to operate the equipment. Virtually no maintenance has been necessary on the equipment. On the first sustained data collection program, the users reported a loss of only 10 seconds of data after testing 60 subjects for a period of ½ hour each.

Flood damage caused by Hurricane Agnes in June 1972 at Cartersville, Va. Note the pins remaining in place while the superstructure and roadway surface in the middle channel are lost.

Benefit-Risk Analysis in the Design of Highway Stream Crossings

by Anthony J. Knepp, Ming T. Tseng, and J. Sterling Jones

Introduction

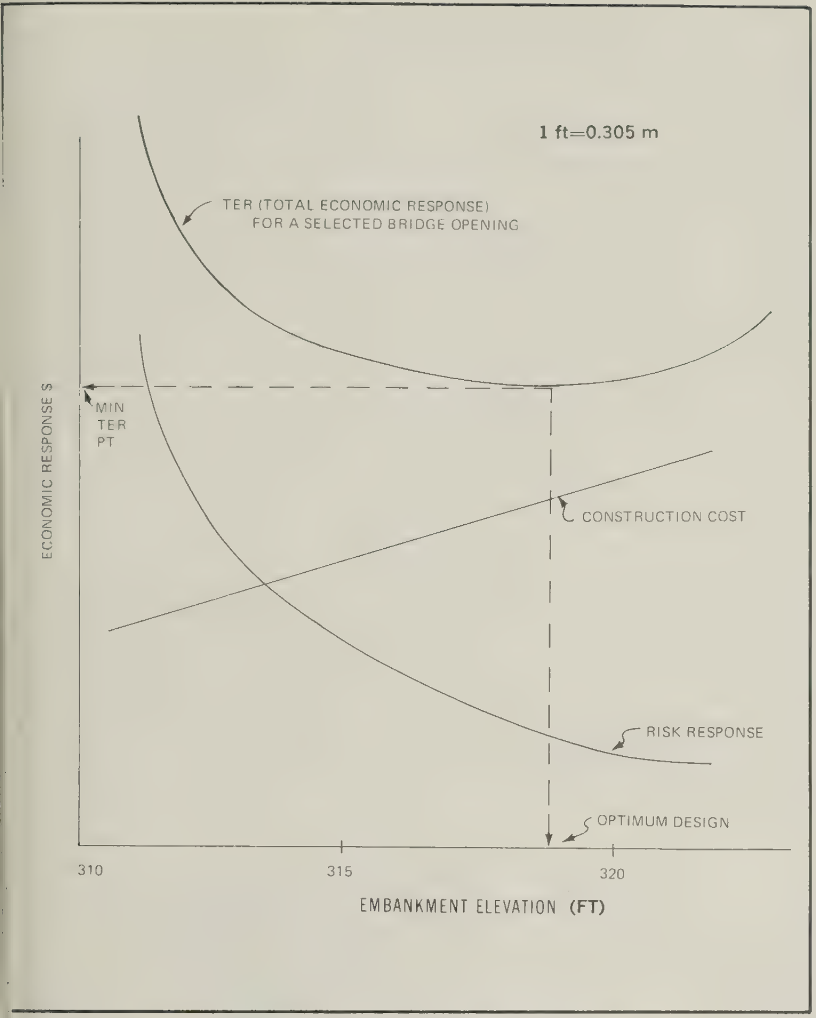
A difficult problem facing the highway engineer is the design of highway stream crossing structures that minimize total cost while maximizing performance. The National Flood Insurance Program has added to this problem by requiring documentation of a structure's hydraulic performance, which must comply with flood plain management regulations in areas designated as flood prone. In practice, engineers tend to comply with flood plain management regulations by sizing structures so that backwater will not exceed some arbitrary limit (for example, 6 in. or 0.15 m) for large floods that have very low probability of occurrence during the life of the project. Similarly, they tend to maximize operational efficiency by elevating highways so that there is a very low probability of traffic being interrupted by flood waters overtopping the highway.

Although these practices have been generally accepted by the engineering profession and by the public, they can often lead to costly overdesign as a direct result of considering one design factor at the expense of others. The ability to pass a given design flood requires the overdesign of the structure in relation to all floods of a lesser magnitude. This also requires a considerable additional investment in the initial construction costs for an event with a low probability of occurrence. The desig of a structure with lower initial cost is counterbalanced by increased damage repair and maintenance costs.

This article is the first of two detailing results of a contrac "Evaluation of Flood Risk Factors in the Design of Highway Crossings," funded by the Federal Highway Administration. The research effort described here represents a large-scale effort in the study and simulatio of backwater and its resultant damages. A future artic will present a summary of the development and application of a finite element solution to the problem of backwater hydraulics.

The Benefit-Risk Concept

Benefit-Risk is the evaluation of the total costs of an alternative design, weighting those costs associated wit probable events by the event's chance of occurrence Figure 1 illustrates the concept of a Benefit-Risk Analy as applied to bridges. The *construction cost* curve represents those fixed costs associated with building bridge and the necessary approach roads and embank-



igure 1.—Conceptual sketch of risk analysis for bridges.

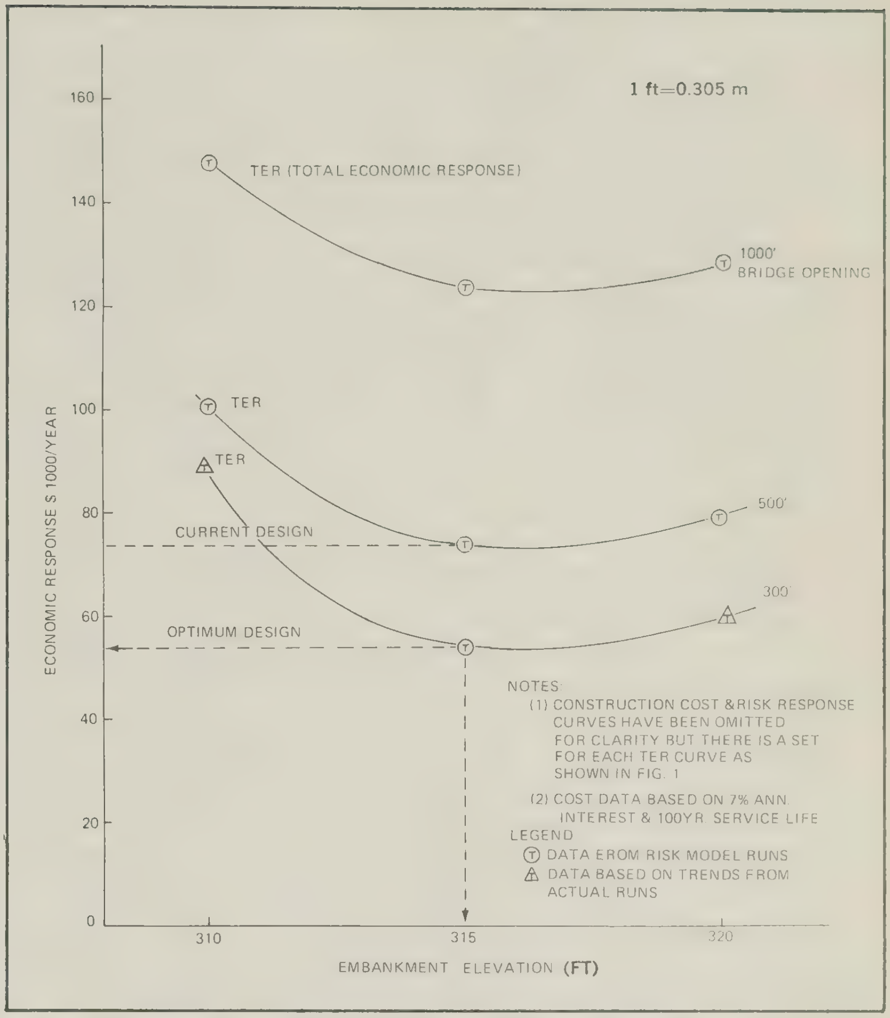


Figure 2.—Sample risk analysis for a highway stream crossing near Tallahalla, Miss.

ıents. Each point on the *risk response* curve represents a ummation of all those costs associated with floods of nown return interval and weighted by the flood's probaility of occurrence. Ideally, each flood capable of causing amage is included in this point. The objective is to evelop an estimate of the expected flood damages both) the bridge and upstream of the bridge for every flood kely to occur. This is done for each configuration of ridge length and embankment height under investigation. he following costs are included in the risk curve: bridge amage from inundation, embankment erosion and ridge pier scour, traffic related losses, and upstream ooding losses. The *total economic response (TER)* curve the sum of the two previous curves. It is the contention f the Benefit-Risk method that the minimum TER point, shown in figure 1, represents the optimal design.

ıe Benefit-Risk concept has been applied to the problem evaluating bridge design in wide, heavily vegetated ood plains. The computer model developed, "RISK," es input economic, hydraulic, and hydrologic data to mulate flow and resultant damages according to the enefit-Risk method. (*1*)[1] Output of the model allows the evaluation of the economic response (cost) of a series of design alternatives. Figure 1 shows the TER for a series of approach embankment elevations for a single bridge opening. Similar TER curves should be plotted for each of several alternate bridge openings to determine the optimum combination of bridge opening and embankment elevation. The optimum combination of the two variables is defined by the minimum point on the lowest TER curve when several curves are plotted.

Example Problem

To illustrate the Benefit-Risk Analysis concept, an example analysis was made for a highway stream crossing near Tallahalla, Miss. The example analysis is based on representative hydrologic, hydraulic, and traffic data for the Tallahalla site, and on construction costs averaged from a large number of Federal-aid bridges.

---

[1] Italic numbers in parentheses identify the references on page 69.

The Risk model was run for several alternate designs including the existing bridge design—a 500-ft (152 m) bridge length and a 315-ft (96 m) embankment elevation. The alternatives included bridge lengths of 1,000, 500, and 300 ft (305, 152, and 91 m) and embankment elevations of 310, 315, and 320 ft (94, 96, and 98 m). The model results (*1*) are plotted in figure 2 which illustrates that the optimal design configuration, among those modeled, is a bridge length of 300 ft (91 m) with an embankment elevation of 315 ft (96 m). The optimal configuration has a total economic response of $20,000 per year less than the existing bridge configuration.

Most designers are accustomed to relating design criteria to some flood return interval. Figure 3 illustrates the return interval associated with one of the elements of design (overtopping of the highway) that is inherent to the Benefit-Risk Analysis. As shown in figure 3 the existing bridge configuration at the Tallahalla site will be overtopped with a 65-year return interval flood, whereas the optimal design configuration based on the Benefit-Risk Analysis would allow the highway to be overtopped with a 50-year flood. Benefit-Risk Analysis does not deal with a single design flood event; rather it deals with all the expected floods weighted by their probability of occurrence. Benefit-Risk Analysis allows the flood return interval associated with various failure modes, such as overtopping of the highway, to be a floating variable; traditional design methods use a predetermined return interval flood to design the bridge configuration.

Related Research

Benefit-Risk Analysis was also applied to the optimum design of box culverts. (2) The 22 test sites used in this study were largely in rural settings where the analysis indicated that optimum design would have resulted in structures smaller than those actually constructed. The opposite finding can be anticipated for many urban sites due to the high risks associated with heavy traffic flows and highly developed commercial and industrial properties.

In the application of Benefit-Risk Analysis to stream crossings, hydraulic behavior was simulated by solving the applicable flow equations using a finite element solution technique. (3) The Finite Element Model (FEM) provides estimates of velocity and depth at locations across the flood plain both upstream and downstream of the construction. The model, with user supplied input, provides a grid which indicates the accuracy of the solution at various locations. Each element of the grid allows the use of individual roughness configurations and ground slopes, thus affecting the conveyance of each model segment. Also the model is capable of estimating the amount of overtopping at specified embankment elevations.

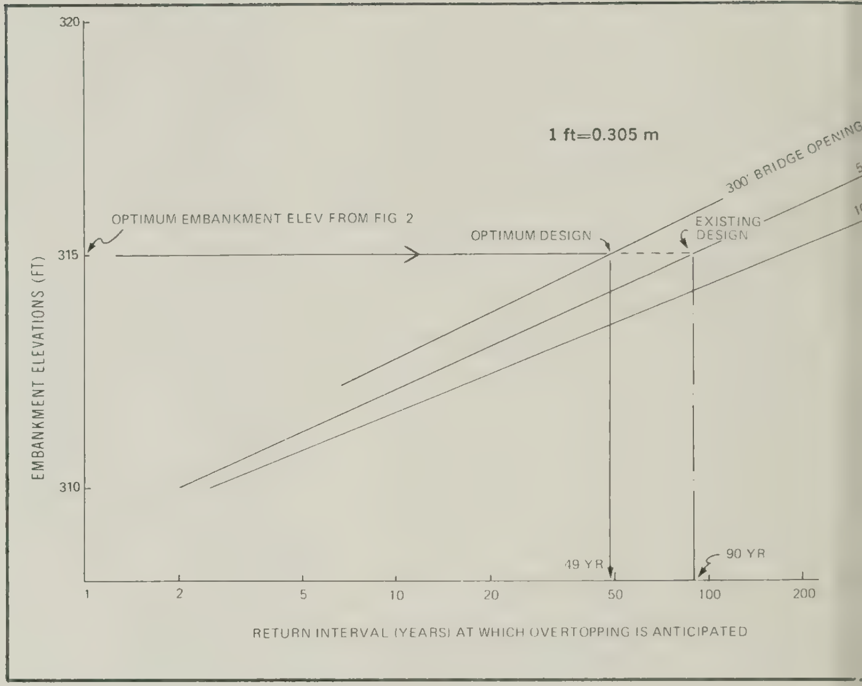


Figure 3.—Optimum design related to flood return intervals for a highway stream crossing near Tallahalla, Miss.

Extensive flume studies of backwater behavior were conducted to provide information needed to validate the FEM. These data (*4, 5*)[2] will provide a basis for possible future development and updating of present backwater estimation methods. A constant-slope flume of approximately 20 by 125 ft (6 by 38 m) was used to test nearly 200 various opening, flow, and physical model configurations. Abutment shapes included wingwall, spillthrough, and both logarithmic and elliptical spurdikes. An important feature of these studies is that different roughness densities were used to better simulate the effects of main channel and flood plain roughness on the location and magnitude of the maximum backwater. Prototype conditions used for design of the flume study were derived from the average of data recorded by the U.S. Geological Survey and reported in Hydraulic Design Series No. 1. (6)

Summary

This work provides the highway engineer with the necessary tools to evaluate a complex problem. It allows him to investigate the various combinations of structure sizes, their initial costs, and their expected flood damage costs. These can be taken together to provide an efficient method for allocating funds for highway stream crossing construction by replacing the concept of a design flood with the efficient use of hydrologic information and probabilities of occurrence, and by evaluating economic response to imposed hydraulic conditions. Thus a rigorous analysis of the hydrology and economics of the situation allows an optimal solution to the problem of backwater caused by highway crossing structures.

---

[2] "Evaluation of Flood Risk Factors in the Design of Highway Stream Crossings. Volume II—Analysis of Bridge Backwater Experiments," Report No. FHWA-RD-75-52 by Water Resources Engineers, Inc., for the Federal Highway Administration. Not yet published.

REFERENCES

(1) M. T. Tseng, A. J. Knepp, and R. A. Schmaltz, "Evaluation of Flood Risk Factors in the Design of Highway Stream Crossings. Volume IV—Economic Risk Analysis for Design of Bridge Waterways," Report No. FHWA–RD–75–54, *Federal Highway Administration,* June 1975.

(2) G. K. Young and M. R. Childrey, "Impact of Economic Risks on Box Culvert Designs—An Application to 22 Virginia Sites," Report No. FHWA–RD–75–49, *Federal Highway Administration,* Washington, D.C., August 1974.

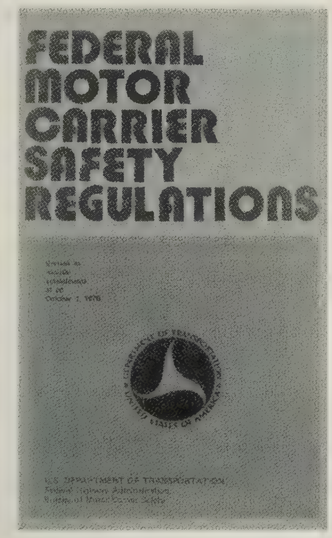
(3) M. T. Tseng, "Evaluation of Flood Risk Factors in the Design of Highway Stream Crossings. Volume III—Finite Element Model for Bridge Backwater Computations," Report No. FHWA–RD–75–53, *Federal Highway Administration,* Washington, D.C., April 1975.

(4) M. T. Tseng, G. K. Young, and M. R. Childrey, "Evaluation of Flood Risk Factors in the Design of Highway Stream Crossings. Volume I—Experimental Determination of Channel Resistance for Large Scale Roughness," Report No. FHWA–RD–75–51, *Federal Highway Administration,* Washington, D.C., August 1974.

(5) M. T. Tseng, J. L. Matticks, and B. Black, "Evaluation of Flood Risk Factors in the Design of Highway Stream Crossings. Volume V—Data Report on Spur Dike Experiments," Report No. FHWA–RD–75–55, *Federal Highway Administration,* Washington, D.C., August 1975.

(6) "Hydraulic Design Series. No. 1—Hydraulics of Bridge Waterways," *Federal Highway Administration,* Washington, D.C., 1970.

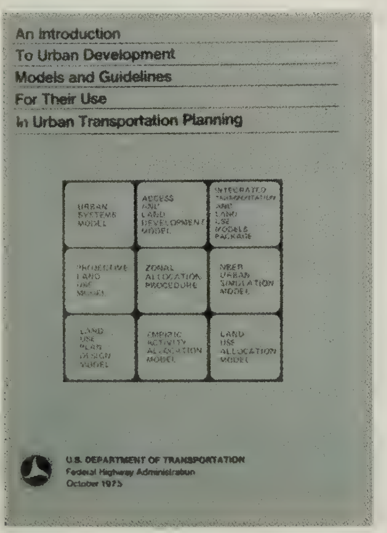
New Publications


FEDERAL
MOTOR
CARRIER
SAFETY
REGULATIONS

U.S. DEPARTMENT OF TRANSPORTATION

Federal Motor Carrier Safety Regulations provides, in one publication, the applicable motor carrier safety regulations for motor carriers operating in interstate or foreign commerce. This is a revised issue of the regulations, including amendments through October 1, 1975, parts 390 through 397. There are sections on qualifications of drivers; driving of motor vehicles; parts and accessories necessary for safe operation; notification, reporting, and recording of accidents; hours of service of drivers; inspection and maintenance; and driving and parking rules when transporting hazardous materials.

This publication may be purchased for $1.80 from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 (Stock No. 050–004–00020–1).


An Introduction
To Urban Development
Models and Guidelines
For Their Use
In Urban Transportation Planning

URBAN SYSTEMS MODEL
ACCESS AND LAND DEVELOPMENT MODEL
INTEGRATED TRANSPORTATION AND LAND USE MODELS PACKAGE
PROJECTIVE LAND USE MODEL
ZONAL ALLOCATION PROCEDURE
NBER URBAN SIMULATION MODEL
LAND USE PLAN DESIGN MODEL
EMPIRIC ACTIVITY ALLOCATION MODEL
LAND USE ALLOCATION MODEL

U.S. DEPARTMENT OF TRANSPORTATION
Federal Highway Administration
October 1975

An Introduction to Urban Development Models and Guidelines for Their Use in Urban Transportation Planning focuses on the urban development model as an operational tool in the urban transportation process. The basic purposes are to provide (1) a general background on the development and use of urban development models, (2) an understanding of the basic principles involved and their operational characteristics, (3) an ability to make enlightened decisions on the evaluation and choice of a model, and (4) information on the practical application of the models. Although the urban development model is suitable for many applications in comprehensive planning, research, and other areas, this report deals primarily with those models and the aspects of the models that are of concern in urban transportation planning.

This publication may be purchased for $2.80 from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 (Stock No. 050–001–00108–0).

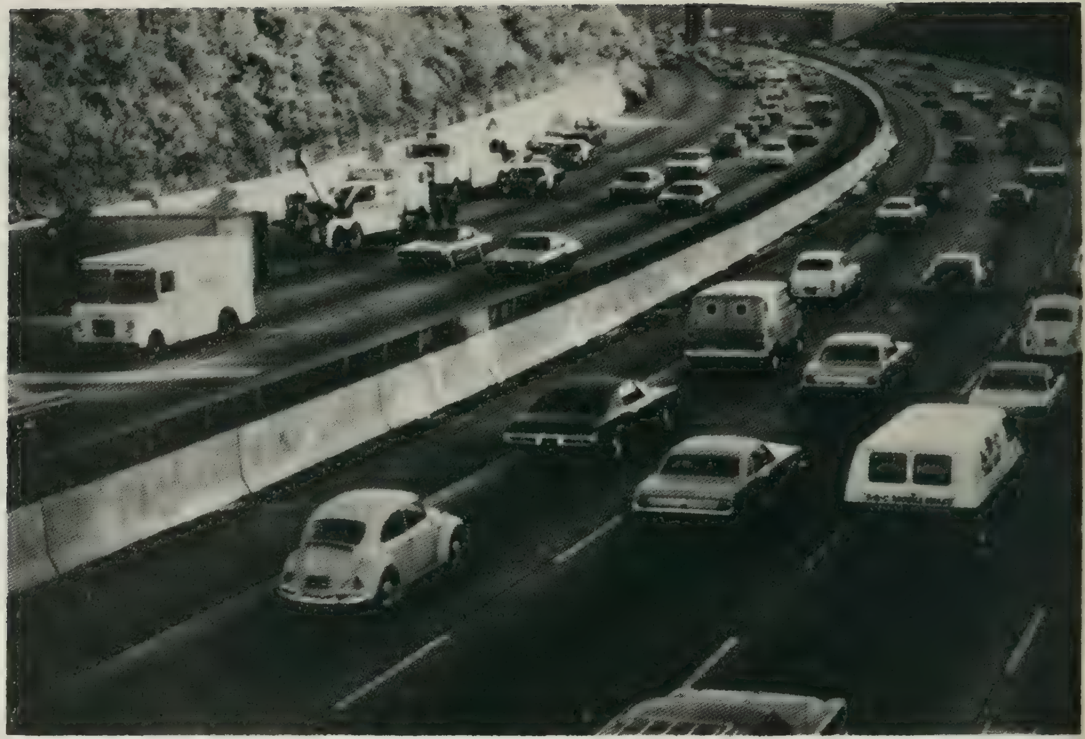


Figure 1.—Freeway traffic congestion caused by overturned vehicle.

Analysis and Remedies of Freeway Traffic Disturbances

by Samuel C. Tignor

One of the research projects in the Federally Coordinated Program of Research and Development (FCP) is Project 1C, "Analysis and Remedies of Freeway Traffic Disturbances." It is concerned with the planning, design, and operation of traffic responsive incident management systems. It also deals with developing guidelines for detecting, locating, and clearing freeway incidents more rapidly, resulting in less delay and fewer chain collisions.

This article describes Project 1C, which is scheduled for completion in 1979.

Introduction

The construction of the interstate highway system and the increased use of motor vehicles has focused attention on highway operation problems which urgently need solving. Many people recognize that because of the over 1 million miles of existing primary and secondary highways, the present level of highway safety and environmental compatibility and the huge outlays for maintenance of pavements and bridges are necessary. In the future, the highway industry must place more emphasis on the development of greater efficiency, safety, and community compatibility in the existing highway systems.

The Federally Coordinated Program of Research and Development (FCP), adopted by the Federal Highway Administration (FHWA), Offices of Research and Development, is a comprehensive, flexible research program designed to solve today's major highway transportation problems. (*1*)[1] One problem area within the FCP is Project 1C, "Analysis and Remedies of Freeway Traffic Disturbances." (*2*) This article describes the organization and goals of Project 1C.

Research Need

Project 1C is oriented toward planning, design, and operation of traffic responsive incident management systems. The development of quicker, more accurate methods to detect and locate freeway incidents will result in a faster response to the scene of breakdowns an accidents, prompt removal of obstructions from the highway, and more efficient control of the situation (fig. 1).

It is estimated that in the United States motorists lose 75 million vehicle-hours per year waiting for freeway incidents to be cleared. (*3*) This results in an annual waste of approximately 400 million gallons of fuel from idling notors at accident sites. Approximately one-half of the lelay on urban freeways is caused by unexpected incidents uch as spilled loads, collisions, and stalled vehicles fig. 2). (*4*)[2]

---

[1] Italic numbers in parentheses identify the references on page 77.

The problem is further illustrated by approximately 2 nillion accidents reported each year on urban freeways. Of these, 41,000 are caused by vehicles already in the oadway. (*3*) Nearly 11 percent of the accidents involve hain collisions. California accident studies show that he accident rate in Los Angeles, where freeway sur-eillance and control have been installed, is down 50 ercent. (*4*) On the Gulf Freeway in Houston, which also as freeway surveillance and control, accidents went rom 145 a year to 75, a reduction of 48 percent. (*5*)

esearch has shown that the loss of a freeway lane ecause of a blockage results in traffic flow loss in more han one lane. For example, the Texas Transportation nstitute found that loss of one lane of a three-lane or our-lane section of freeway reduces traffic flow by 50 and 3 percent, respectively. (*6*)

isabled or stopped vehicles also cause freeway lane lockages. A California study showed that one vehicle op occurs every 18,000 vehicle-miles (28,800 km) for arious reasons, such as map reading, mechanical roblems, and driver desire. One vehicle stop occurs only very 26,000 vehicle-miles (41,600 km) due to mechanical isablement. (*7*)

About 34 percent of the disablements are due to mechanical breakdowns. Flat tires (27 percent) are next, followed by fuel depletion (13 percent), overheating (10 percent), electrical system (7 percent), and other problems (9 percent).[3]

The importance of freeway traffic management and control is widely recognized. In the 1973 Highway Act Congress sought means for encouraging greater citizen participation in the programs emphasizing accident detection, response, and reporting. (*8*) The Transportation Research Board's Freeway Operations Committee recently gave traffic management and control top priority out of 20 problems needing research. (*9*)

Approach to Problem

Regardless of the kind of incident management system, some form of freeway surveillance is needed. This may be provided by loop detectors, police, telephone, call boxes, service patrols (fig. 3), or possibly citizens' band radios. Once an incident has been detected and confirmed (not a false alarm), some form of incident management strategy must be employed. The type of corrective measure used depends on the type and seriousness of the incident and the kind of controls available for maintaining freeway flow. Typically, the incident is removed and where surveillance and control systems are in operation, restrictive ramp metering or route diversion may be used. The corrective measure selected should restore the freeway to normal operations as soon as possible.

ure 2.—Removal of debris on the roadway can cause traffic con-tion and delay.

Figure 3.—Motorist service patrols deter congestion by quickly removing stranded vehicles from the roadway.

'Developing an Effective Freeway Traffic Management System for s Angeles," by W. Schaefer and J. West, California Division of Highays. A report presented in a joint session of two AASHO committees: ommunication and Electronics Committee and Traffic Committee, ov. 10, 1970, Houston, Tex.

[3] "Surveillance and Control for Incidents on Chicago Area Freeways," by J. M. McDermott. Presented at the Transportation Research Board's Mid-Year Meeting, Jacksonville, Fla., Aug. 5–7, 1974.

To minimize delay and disruption of traffic, incident management strategies can make good use of preplanned, stand-by procedures. Interagency and jurisdictional agreements can be preplanned and formulated to define the roles and responsibilities of individual agencies. Electronic surveillance systems can be used along sections of freeway or at selected points experiencing recurring trouble. Ramp control options can be planned to preregulate flow according to the seriousness of the freeway incident.

The basis of Project 1C is to formulate and test methods for maintaining stable traffic flow conditions on high demand freeways and to minimize the seriousness, inconvenience, and duration of freeway incidents.

Major research efforts are represented in four tasks:

- Freeway Traffic Modeling—Existing simulations will be adapted and modified to permit the study of control strategies used with incident detection algorithms. Methodology for proper validation of the models will also be developed.
- Freeway Control Experimentation—This task includes three sequential steps: (1) select one or more sites for evaluating freeway incident remedial concepts, (2) develop software and hardware specifications for implementing incident management concepts, and (3) experimentally test concepts on freeway site(s).
- Strategies and Criteria for Their Use—This task provides for development of computerized incident detection algorithms based on time serial changes of traffic parameters. It also provides for development of incident management concepts using techniques such as variable message signing, roadside radio communication, service patrols, and other methods of surveillance and incident management.
- Human Factors—This task incorporates the following: (1) analysis of human factor requirements for incident management, (2) development of information displays, (3) evaluation of information displays, and (4) recommendations for the design of signs—both onsite and portable—to be used with incident management systems.

The FCP approach encourages the coordinated use of multisource funds. Consequently, Project 1C studies are supported by administrative contract, FHWA staff research and development, Highway Planning and Research (HP&R), National Cooperative Highway Research Program (NCHRP), and, in special situations, construction funds. A major requirement of the project is to marshal these resources into a successfully coordinated research program.

Table 1.—Projected completion dates for individual studies

Study	Type	Projected completion date
Freeway Traffic Modeling, Task 1		
Parameter Estimates from Detector Data	HP&R	Completed
Analysis of Lane Blockage for Freeway Traffic Control	Contract	Completed
Adaptation of a Freeway Simulation Model	Contract	February 1977
Freeway Control Experimentation, Task 2		
Field Test and Evaluation of Improved Detection Algorithms	HP&R	July 1977
Alternative Surveillance Concepts and Methods	Contract	February 1977
Evaluation of Alternative Surveillance Methods	HP&R	September 197
Design Guides for Incident Detection and Management Systems	Planned Contract	November 197
Development and Evaluation of On-Freeway Traffic Control Systems and Surveillance Techniques	HP&R	September 197
Strategies and Criteria for Their Use, Task 3		
Data for Development of Incident Detection Algorithms	Contract	September 197
Development and Testing of Incident Detection Algorithms	Contract	Completed
Study of Traffic Flow on a Restricted Facility	HP&R	September 19
Design and Operation of Ramp Control Projects	NCHRP	Completed
Development and Testing of Control Strategies for Freeway Incident Management	Planned Contract	March 1978
Optimal Design and Operation of Freeway Incident Service Systems	Contract	Completed
Human Factors, Task 4		
Human Factors for Real-Time Motorist Information Systems	Contract	May 1977
An Effective Warning Information System for the Motorist	HP&R	September 19

Individual Studies Within Project 1C

Each task is composed of individual study efforts whic will help develop system recommendations and design guides. Table 1 and the following paragraphs describe t major studies within each task and their projected completion date.

Freeway Traffic Modeling (Task 1)

Parameter Estimates for Detector Data. This complete study evaluated techniques for estimating traffic parameters such as density, speed, and total travel ti from presence detector data. (*10*) Procedures are given determining the relationship between occupancy and density, frequently known as the G-factor.

Analysis of Lane Blockages for Freeway Traffic Control study was completed which analytically described traf density buildup following a lane blockage on a four-lan freeway under light traffic conditions. A system of differential equations was developed and solved. The formulation allowed for both upstream and downstream traveling waves from the location of lane blockage. *(11, 12)*

Adaptation of a Freeway Simulation Model. A freeway simulation model, coded in FORTRAN, is being developed for the study of freeway control strategies and incident detection algorithms. The model will provide for roadway geometrics such as lane drops, lane additions, on and off ramps with variable spacings, auxiliary lanes, and horizontal and vertical curves as found on freeways. The model, when completed, will be operable in the range of 0 to 2,200 vph per lane for 4- to 10-lane freeways. Model outputs will include vehicle delay, exhaust emissions, and fuel consumption.

Freeway Control Experimentation (Task 2)

Field Test and Evaluation of Improved Detection Algorithms. This HP&R research will permit State freeway surveillance and control systems to measure and evaluate the effectiveness of the new incident detection algorithms relative to traffic, geometric, and environmental conditions. Since State organizations will be the ultimate users of the research, their findings and recommendations are expected to be invaluable. The Illinois Department of Transportation is presently evaluating, in an HP&R research study, new incident detection algorithms.

Alternative Surveillance Concepts and Methods. This ongoing research study concerns identifying and developing low cost incident management systems for responding to freeway disturbances. The systems to be developed are expected to have particular application for small, urban traffic departments with limited financial resources. Emphasis is being placed on development of the following: preplanning response techniques; candidate jurisdictional agreements; surveillance inputs and networks; communication links to and from a management control center; candidate response systems; traffic operational procedures for site management; and new techniques which can be easily implemented and used. Overall guidelines and recommendations will be documented for four management systems each representing a different level of investment.

Evaluation of Alternative Surveillance Methods. This proposed HP&R study will provide for the testing and evaluation of low cost incident surveillance concepts and methods. At least one of the four management methods developed under the study *Alternative Surveillance Concepts and Methods* will be implemented and evaluated. A cost-effectiveness analysis will be performed and recommendations for large-scale implementation provided.

Design Guides for Incident Detection and Management Systems. This study will be the last phase of research under Project 1C. It will integrate findings from the algorithms and control strategy developments, roadside audio and visual signing requirements, alternative surveillance concepts, and roadside service components of an incident management system. This effort will delineate and document the communication and hardware requirements necessary to implement typical incident management systems. Functional hardware and software specifications and typical installation and operation plans will be documented.

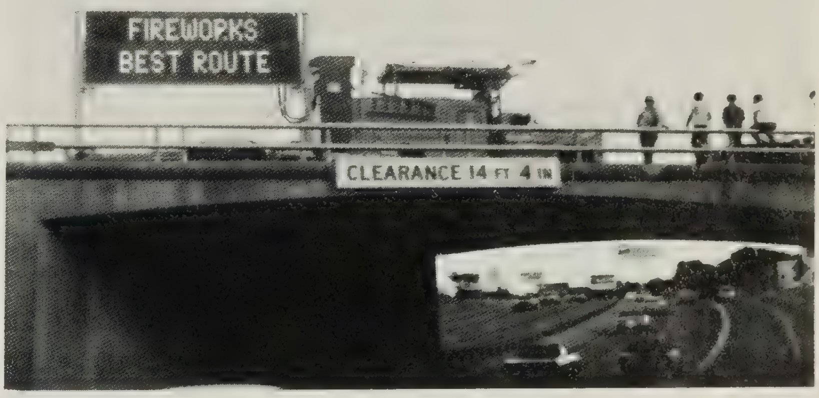


Figure 4.—Experimental trailer mounted motorist information sign used in a Texas research study.

Development and Evaluation of On-Freeway Traffic Control Systems and Surveillance Techniques. In this HP&R research study, the use of an on-freeway lane closure system will be evaluated in Houston, Tex., by the Texas Transportation Institute for the Texas Highway Department. The purpose of the system is to adjust on a real-time basis the capacity of a freeway-to-freeway merge area so as to improve the traffic operations within an interchange experiencing extensive peak-period congestion.

Other study phases emphasize (1) development of motorist information systems for use on elevated freeways, causeways, and tunnels, and (2) evaluating the cost and effectiveness of closed-circuit television to survey traffic operations over large freeway networks. An example of a roadside motorist information system, which is being evaluated by Texas Transportation Institute, is shown in fig. 4.

Strategies and Criteria for Their Use (Task 3)

Data for Development of Incident Detection Algorithms. This study has provided freeway data sets of 150 incidents and 50 nonincidents from the 42-mile (67 km) Los Angeles surveillance and control system. An additional 85 data sets will be obtained from closely spaced (600 feet, 183 m) detectors located on a 1-mile (1.6 km) northbound section of the San Diego Freeway. All of the vehicle detector crossings will be stored on magnetic tape.

Development and Testing of Incident Detection Algorithms. In this completed study the effectiveness of presently available incident detection algorithms for medium and heavy traffic flow conditions was evaluated and new algorithms were developed. (*13*) The effect of sensor configuration, geometrics, and weather conditions was also evaluated. Other study reports have been published on detecting freeway incidents under low volume traffic conditions. (*14, 15*)

Study of Traffic Flow on a Restricted Facility. This Maryland HP&R study concerns traffic flow improvements for tunnels and other restricted facilities. Research will be conducted and recommendations made relative to the location and type of upstream traffic controls, toll plaza operations, and within-tunnel operations and control systems. (*16*)

Design and Operation of Ramp Control Projects. In this NCHRP study, design guidelines and recommendations were developed for ramp control systems. Emphasis is placed on integration of electronic hardware, system control logic, and specifications for optimum throughput, and development of system specifications which permit follow-up system improvements such as real-time surveillance and control.

Development and Testing of Control Strategies for Freeway Incident Management. Most ramp control systems are not coordinated with incident detection algorithms and thus ramp control is not implemented except during peak traffic periods. This proposed research will develop and evaluate ramp control strategies that can be implemented when freeway incidents occur. Recommendations will be developed for conditions when the various control strategies should be used.

Optimal Design and Operation of Freeway Incident Service Systems. This completed research study provides procedures for (1) designing freeway emergency vehicle service systems, and (2) developing systems for managing freeway disturbances using cost-effectiveness techniques. Various approaches are considered for providing real-time control during freeway disturbances. (*17*)

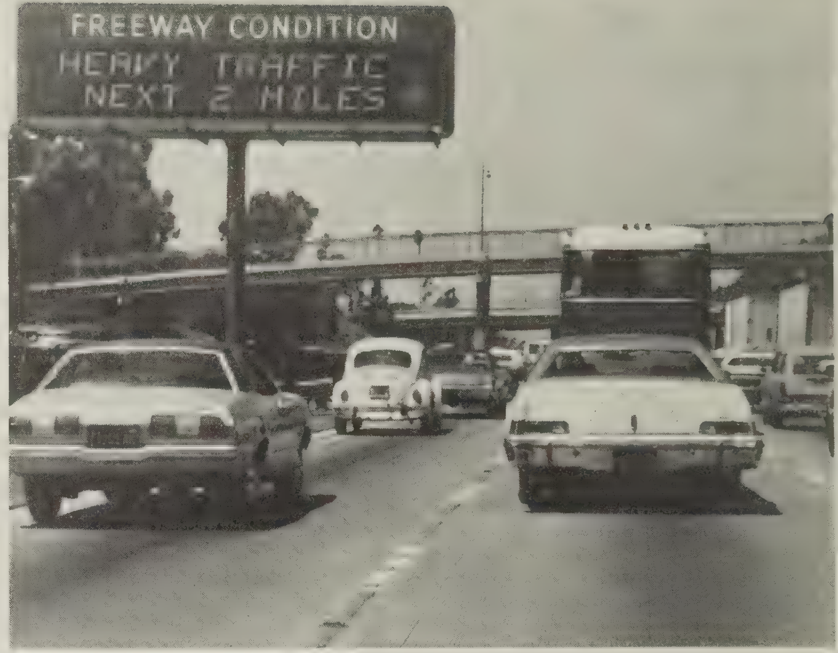


Figure 5.—A variable message sign system being evaluated in California.

Human Factors (Task 4)

Human Factors for Real-Time Motorist Information Systems. For an incident management system to be effective, methods must be available to communicate information to drivers. A critical problem in this task is to determine the kind of information that should be reported to drivers and how it should be presented. In this research, a series of variables pertaining to the understanding and efficiency of audio and visual messages is being evaluated for use during freeway incidents. Design specifications and recommendations will be made for information content, format, placement, quantity, and redundancy. Instrumented vehicles, laboratory investigations, and traffic evaluation methods are being used in the research studies.

An Effective Warning and Information System for the Motorist. An HP&R analysis is being performed by the California Department of Transportation on the Los Angeles freeway surveillance and control system for developing motorist information systems. (*18*) The motorist's desire for current traffic information is being evaluated relative to changeable message signs, roadside radio, and commercial radio information broadcasts (fig. 5). The effect of each type of information media on delay, accidents, and driver aggravation is being considered.

Recent Important Achievements

Major achievements have been made recently in freeway management, control, and operation. These include (1) the expansion or implementation of surveillance and

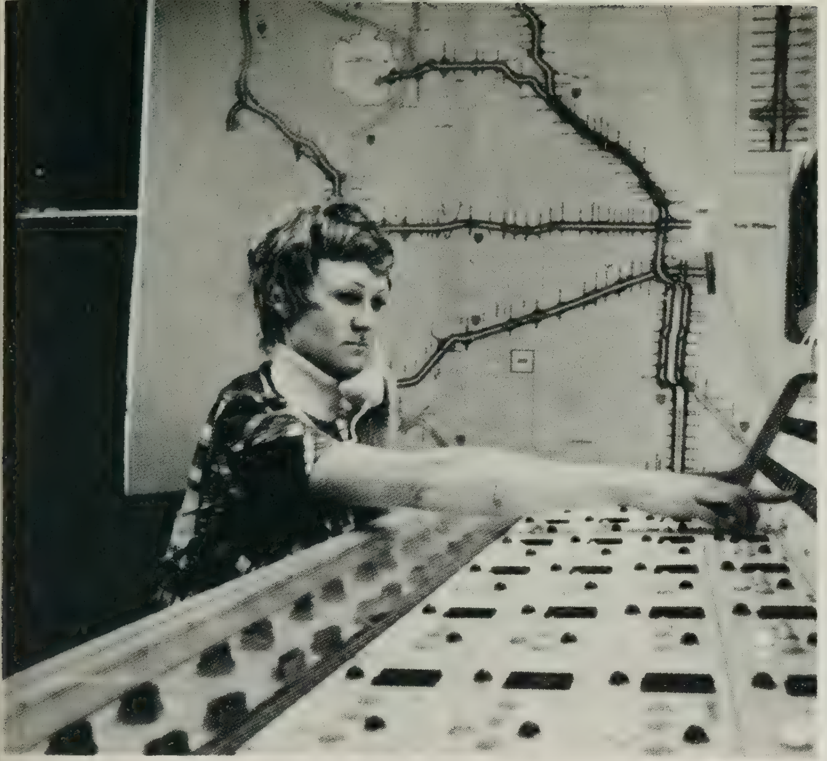


Figure 6.—Current traffic information is transmitted to local radio and television stations from the Chicago surveillance control center.

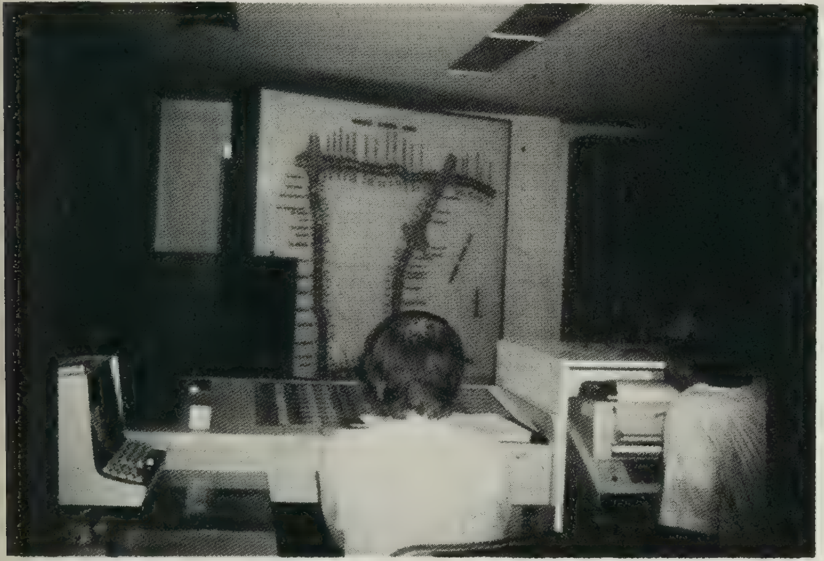


Figure 7.—The traffic surveillance board used in monitoring the 42-mile Los Angeles control system.

control systems which incorporate incident detection, (2) development of preplanned incident management methods, and (3) off-freeway accident investigation sites.

This section will briefly discuss these new activities. Earlier freeway surveillance and control techniques are discussed by Everall in his report "Urban Freeway Surveillance and Control." (*19*)

A continuing effort is being made to expand some of the established surveillance and control systems. For example, the Illinois Department of Transportation operates the Chicago Area Expressway Surveillance Project which, with over 1,300 detector locations, provides surveillance on 196 directional miles (315 directional kilometers) of expressway.[3] This coverage involves eight major expressways on a network that handles up to 267,000 vehicles per day in some sections. A total of 48 on-ramps are equipped to meter traffic. The control center also provides real-time computer generated traffic information via a teleprinter to Chicago area radio and television stations to advise drivers of traffic situations (fig. 6).

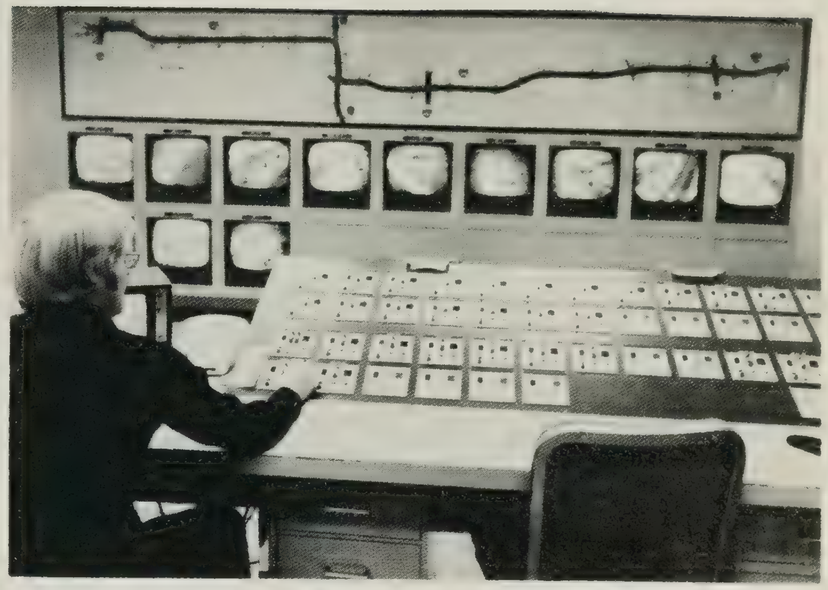


Figure 8.—The Minneapolis traffic surveillance control center.

The California Department of Transportation has also enlarged the 42-mile (68 km) Los Angeles Area Freeway Surveillance and Control System. (*4, 20*) It includes segments of three major freeways carrying as many as 240,000 vehicles per day in some sections (fig. 7). A total of 20 on-ramps meter vehicles in traffic responsive modes; an additional 32 ramps are metered in fixed-time control. Some metered ramps have priority lanes for buses and carpools. As in Chicago, traffic information is provided by the control center to Los Angeles area radio and television stations via a teleprinter. Tests are being made on the effectiveness of 35 real-time variable message driver information signs located in the median about every 4,000 feet (1,220 m). (*4, 18*)

One of the newest traffic surveillance and control systems is in Minneapolis. (*21*) It oversees traffic operations on sections of I–94 and I–35W which handle an average daily traffic (ADT) of 130,000. The major system components provide for the metering of 37 ramps, operation of 5 real-time changeable message signs, over 300 computerized induction loop detectors for use in locating freeway incidents, and 24 closed-circuit television cameras for incident confirmation (fig. 8).

"Surveillance and Control for Incidents on Chicago Area Freeways," by J. M. McDermott. Presented at the Transportation Research Board's Mid-Year Meeting, Jacksonville, Fla., Aug. 5–7, 1974.

Table 2.—Freeway Surveillance and Control Systems

Location	Total freeway directional miles	TV cameras	Number of ramps controlled	Number of variable message signs
Chicago, Ill.	196	None	48 ramps metered	None
Cincinnati, Ohio	5	6	None	19
Dallas, Tex.	20	9	34	3 rotating drums on surface streets
Denver, Colo.	16½	None	None	4
Houston, Tex.	[1] 6½ [2] 10	12 0	9 20	3 0
Los Angeles, Calif.	84	None	52	35
Minneapolis/ St. Paul, Minn.	37	24	40	8

[1] Gulf Freeway (Prior to 1975–76 Reconstruction). 1 mile=1.6 km

[2] Southwest Freeway, U.S. 59.

In the modern Minneapolis system, all communication and telemetry equipment is located on the floor under the control center. This arrangement provides improved system flexibility and operation. Project emphasis is on developing high transit level service by providing express bus priority access to the freeway, rapid detection of incidents, and communication of freeway traffic conditions to transit officials.

Other freeway control systems have been expanded or implemented. Table 2 identifies these facilities and summarizes their major features.

Traffic delay caused by freeway incidents can be minimized by preplanned incident management methods. Such plans can be exercised to rapidly restore the freeway to its normal operation. The California Department of Transportation has developed an incident response team for use when major freeway incidents occur.[5] The procedure involves developing alternate routes for the temporary bypass of an incident blocking two or more lanes of a four-lane, one-direction freeway. The incident response team sets up a command post where operations for police, fire, and maintenance units are coordinated to restore freeway traffic operations.

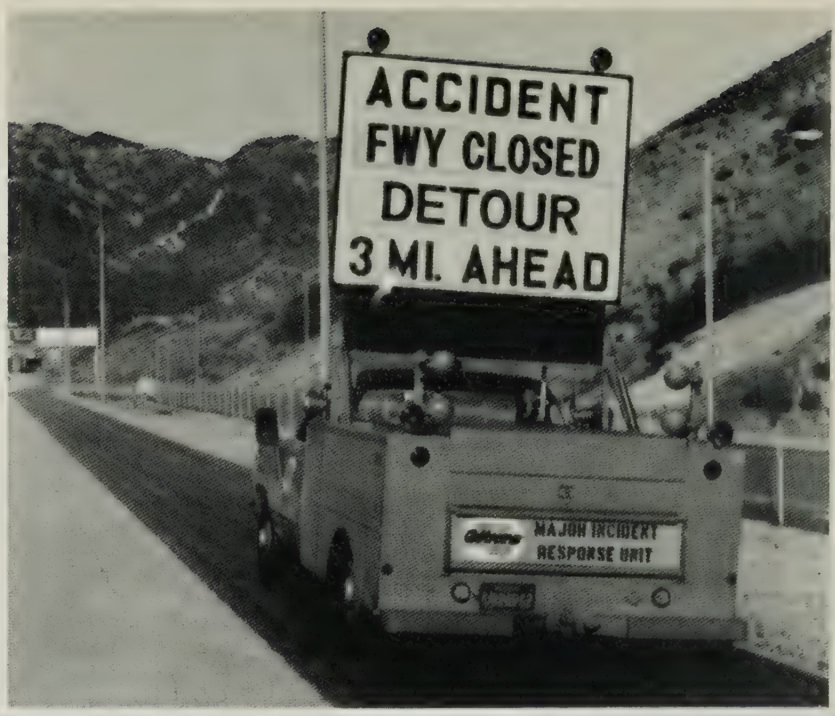


Figure 9.—Traffic messages are quickly developed with fabric signs used by the California incident response teams.

The 10-man response team uses three alternate route signing vehicles and three variable message sign trucks, four communication vehicles, and special signs that can be mounted temporarily on existing poles or special stands. Both metal and fabric signs are used (fig. 9). The response team has responded to about 10 major incidents per month since October 1972. The average monthly delay of these major incidents is about 17,000 vehicle-hours, which is about 15 percent less than before the response teams were organized.

Freeway accidents can also lead to slowdowns brought on by gawking motorists. To overcome this, a new technique, known as off-freeway accident investigation, was developed under an HP&R study by the Texas Transportation Institute for the Texas Highway Department. It stresses removal of the affected vehicles before accident investigations are made. (22) Interviews and investigation forms are completed away from the freeway. Typical sites may be unused land under a freeway overpass, some other unused right-of-way, or lightly traveled city streets or service roads. The amount of freeway congestion and delay caused by an accident depends on the length of time the vehicles involved block a lane or are visible to other motorists. An average of 25 minutes is required for completing minor accident investigations. Reduction in delay, through employment of 93 off-freeway accident investigation sites, along the Gulf Freeway in Houston in 1971 and 1972, was about 29,250 vehicle-hours. Secondary accidents were reduced by approximately 21 percent. The average installation cost of each investigation site was about $2,500. The benefit to cost ratio was determined to be greater than 28 to 1.

Concluding Project Phases

Numerous studies are included in Project 1C. It is desirable to fully test and evaluate each individual research study component. As noted, some of the individual studies are followed by HP&R evaluations for the purpose of obtaining early State experience and recommendations since the States are the ultimate users of the research.

---

[5] "Alternate Routes are Recommended," by D. H. Roper, California Division of Highways. A report presented to the Highway Research Board, Freeway Operations Committee, Columbus, Ohio, June 27, 1973.

t is also desirable to evaluate the overall effectiveness of he Project 1C freeway management concepts on an ntegrated basis. Field tests and evaluations are expected o be conducted in conjunction with the planned ntegrated Motorist Information System (IMIS) demonstration (23) to be located on Long Island, N.Y. It is part of CP Project 2C, "Requirements for Alternate Routing to Distribute Traffic Between and Around Cities," and is ntended to be operational by 1981.

he Implementation Division of FHWA's Office of Development is the coordinator of the implementation hase of Project 1C. This phase will emphasize development and distribution of special user documents to assist n implementing many of the results from the previously lescribed studies. All research developments of Project C are scheduled for completion by 1979.

cknowledgments

ppreciation is extended to Richard H. Green, Richard J. Murphy, and Dan Link, California Department of Transportation; Joseph A. Wattleworth, University of Florida; oseph M. McDermott, Illinois Department of Transportation; G. C. Carlson, Minnesota Highway Department; nd Conrad L. Dudek, Texas A&M University, for the hotographs used in this article.

EFERENCES[6]

) "Federally Coordinated Program of Research and Development in ighway Transportation, Introduction and Summary," *Federal Highway dministration*, November 1972.

) "Federally Coordinated Program of Research and Development in ighway Transportation, Volume 1—Improved Highway Design and peration for Safety," *Federal Highway Administration*, January 1975,). 41–68.

) Harold Lunenfeld, R. G. Varady, and G. N. Newburg, "Post-Crash ommunications," *National Highway Safety Bureau*, July 1970, pp. -36.

) K. A. Godfrey, "Los Angeles Tackles Freeway Congestion," *Civil gineering*, vol. 45, No. 9, September 1975, pp. 96–100.

) J. H. Buhr, "Freeway Ramp Control," *Civil Engineering*, vol. 38,). 6, June 1968, pp. 36–39.

M. E. Goolsby, "Influence of Incidents on Freeway Quality of rvice," Highway Research Record 349, *Highway Research Board*, 71, pp. 41–46.

(7) H. Sarkinson and K. P. Meyers, "Service for the Stranded Motorist Project," *California Division of Highways*, July 1972.

(8) "The 1973 Federal-Aid Highway Act, An Analysis," *Federal Highway Administration*, 1974, p. 13.

(9) Highway Research Circular No. 132, *Highway Research Board*, April 1972, p. 5.

(10) H. J. Payne, "Analysis and Evaluation of Estimators of Traffic Parameters," *California Department of Transportation*, 1973.

(11) D. Kahn and R. Mintz, "Freeway Traffic Flow Following a Lane Blockage," Transportation Systems Center, *Federal Highway Administration*, July 1973. PB 222399.

(12) D. Kahn, et al., "Lane Blockage Effects on Freeway Traffic Flow," Transportation Systems Center, *Federal Highway Administration*, January 1974. PB 228991.

(13) "Development and Testing of Incident Detection Algorithms," *Federal Highway Administration*, vols. 1–4.

Vol. 1—H. J. Payne, "Summary of Results," FHWA–RD–76–19, April 1976.

Vol. 2—H. J. Payne, E. D. Helfenbein, and H. C. Knobel, "Research Methodology and Detailed Results," FHWA–RD–76–20, April 1976.

Vol. 3—H. J. Payne and H. C. Knobel, "User Guidelines," FHWA–RD–76–21, April 1976.

Vol. 4—H. J. Payne and E. D. Helfenbein, "Program Calibration for Evaluation, Calibration, and Implementation," FHWA–RD–76–22, April 1976.

(14) C. L. Dudek, C. J. Messer, and N. B. Nuckles, "Incident Detection on Urban Freeways," Transportation Research Record 495, *Transportation Research Board*, 1974, pp. 12–24.

(15) C. L. Dudek, G. D. Weaver, G. P. Ritch, and C. J. Messer, "Detecting Freeway Incidents Under Low Volume Conditions," Transportation Research Record 533, *Transportation Research Board*, 1975, pp. 34–47.

(16) E. C. Carter, "Study of Traffic Flow on a Restricted Facility," Interim Report—Phase 1, *Maryland State Highway Administration*, June 1973.

(17) A. D. May, et al., "Optimal Design and Operation of Freeway Incident Detection Service Systems," *Office of the Secretary, U.S. Department of Transportation*, February 1975. PB 243384.

(18) Michael A. Bogdanoff and R. Patton Thompson, "Evaluation of Warning and Information Systems. Part I—Changeable Message Signs," *State of California Business & Transportation Agency, California Department of Transportation*, July 1976.

(19) Paul F. Everall, "Urban Freeway Surveillance and Control—State of the Art," *Federal Highway Administration*, November 1972.

(20) "Los Angeles Area Freeway Surveillance and Control Project," *State of California, Department of Public Works*, Second Annual Report, January 1972.

(21) G. C. Carlson and R. J. Benke, "I–35W Urban Corridor Demonstration Project Surveillance and Control System Overview," *Minnesota Highway Department*, May 1973.

(22) Mary Ann Pittman and Roy C. Loutzenheiser, "A Study of Accident Investigation Sites on the Gulf Freeway," *Texas Highway Department*, August 1972. PB 223583.

(23) M. F. Maloney, H. A. L. Lindberg, and G. W. Cleven, "A Solution to Intercity Traffic Corridor Problems," *Public Roads*, vol. 37, No. 5, June 1973, pp. 173–184.

---

[6] eports with PB numbers are available in paper copies and micro-he from the National Technical Information Service, 5285 Port Royal l., Springfield, Va. 22161.

Highway Design for Motor Vehicles—A Historical Review

Part 7: The Evolution of Highway Grade Design

by[1] Frederick W. Cron

This is the seventh in a series of eight historical articles tracing the evolution of present highway design practices and standards in the United States. The Introduction and Part 1: The Beginnings of Traffic Measurement were published in vol. 38, No. 3, December 1974. Part 2: The Beginnings of Traffic Research was published in vol. 38, No. 4, March 1975. Part 3: The Interaction of the Driver, the Vehicle, and the Highway was published in vol. 39, No. 2, September 1975. Part 4: The Vehicle-Carrying Capacity of the Highway was published in vol. 39, No. 3, December 1975. Part 5: The Dynamics of Highway Curvature was published in vol. 39, No. 4, March 1976. Part 6: Development of a Rational System of Geometric Design was published in vol. 40, No. 1, June 1976. Part 8: The Evolution of Highway Standards is to be published in a future issue.

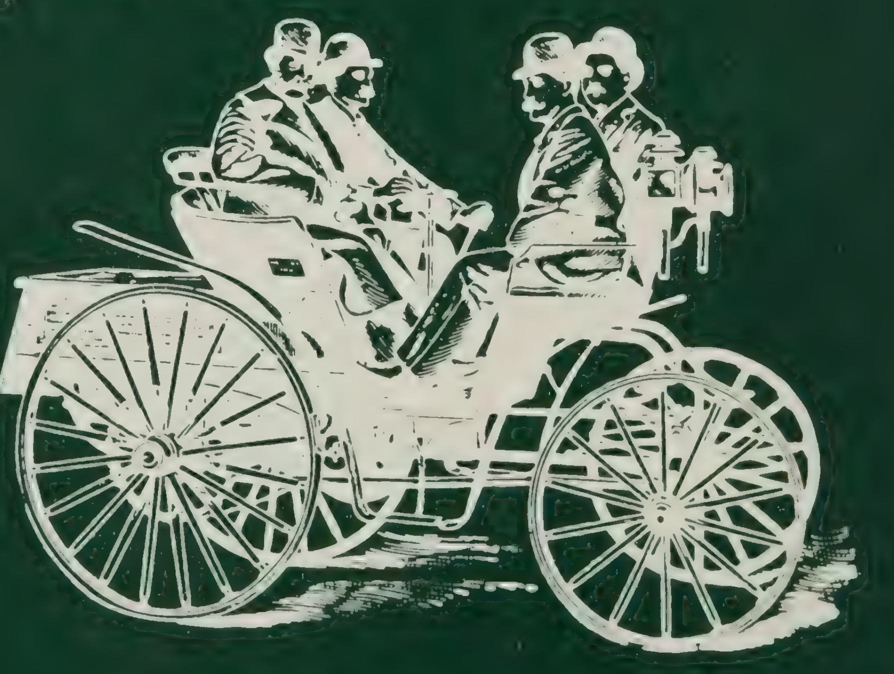
Early Studies of Road Grades

The systematic study of road grades began in the early 19th century, coincident with the surfacing with stone of the principal roads in Europe and England. Prior to this surfacing, the loads that could be hauled on the highways depended more on the condition of the road surface than on its gradient. Often, the most difficult sections to traverse were the low, poorly drained, level valley sections where the road might be a rutted quagmire, while the steeper, better drained sections were naturally easier to travel. When the roads were graded and surfaced, the reverse became true, focusing unfavorable attention on the hills.

About 1835, John Macneill, a Scotsman, made a recording dynamometer with which he could measure the tractive effort required to draw a load over road surfaces of varying roughness and gradient. This was a powerful spring balance operating in a cylinder filled with oil which was placed between the test vehicle and the team supplying the traction. With this machine, Macneill measured the pull exerted by the team in drawing a 2,400-pound wagon over various level roads as follows:

- Gravel road on earth foundation—147 lbs or 1/16 of the gross load.
- Broken stone road on earth foundation—65 lbs or 1/36 of the gross load.
- Broken stone on paved foundation—46 lbs or 1/51 of the gross load.
- Well-made pavement—33 lbs or 1/71 of the gross load.
- Best stone trackways—12 1/2 lbs or 1/179 of the gross load. (*1*)[2]

Other investigators of the period—notably Parnell in England, and Poncelet and Morin in France—found that the *traction* or effort required to pull a vehicle on a road depended not only on the nature of the road surface, but also on the diameter of the vehicle wheel, the width of tire, and to a slight extent on the velocity of travel, being greater for vehicles drawn at a trot than at a walk. (*1*) This last may be the first measurement of vehicular wind resistance.



---

[1] Frederick W. Cron's biography appeared with part 1 of his article in vol. 38, No. 3, December 1974.

[2] Italic numbers in parentheses identify the references on page 86.

To draw the test wagon up a grade[3] an extra effort was required, which, as was already well known from the laws of mechanics, depended on the steepness of the gradient and the weight of the load, and could be figured by the formula:

$$F=W\frac{h}{l}$$

Where,

F=Force exerted parallel to the road surface.

W=Weight of the wagon and its load.

h=Rise through which the wagon is raised.

l=Distance measured on the road surface corresponding to the rise h.

Thus, if friction and road resistance are disregarded, the force required to pull a wagon up a 1 in 20 gradient (or to keep it from rolling down the slope) would be 1/20 of the weight of the wagon and its load.

In the era of animal power the *angle of repose* was the desirable maximum gradient angle for descending grades. This was the angle at which the tractive resistance just balanced the force of gravity, and ideally was the slope on which a carriage and team could descend safely at a trot without using the brakes. The angle of repose depended on the road surface and for good macadam was equivalent to a slope of about 1 in 35 or approximately 2.85 percent. This was the preferred gradient for post roads where speed of travel was important, and on such a slope a coach could be safely drawn downhill at a speed of 12 mph. (*1*)

On the other hand, if the gradient were steeper than the angle of repose, the driver would have to slow down to half speed or less and use his brakes to control the vehicle. The time so lost might justify the selection of a longer but less steep route for the road.

Animal Traction Limits

The tractive power of draft animals placed a limit on ascending gradients. An ordinary team of horses weighing 2,400 pounds could be counted on to exert a pull of about 240 pounds traveling at 3 mph for a 10-hour day. This effort would pull a gross load of 6 tons on a level macadam road. (2)

On grades, horses could increase their effort; and, if the gradient were not more than about 2.5 percent, continue to draw about as much load as on the level. However, for steeper gradients their pulling power diminished from exhaustion while at the same time the force to be overcome increased, so that at 5 percent gradient a 2,400-pound team could haul only about 3.4 tons on macadam, and at 7 percent only 2.4 tons. The tonnage that could be hauled over a road therefore depended on its steepest grades, for it was uneconomical to reduce loads for these grades, or, even worse, to hitch on an extra team that would be needed in only a few places.

Thus, the ideal maximum gradient to meet the requirements of both tractive effort and safe descending speed was between 2.5 and 3.0 percent. Thomas Telford, one of the founders of highway engineering, was a firm believer in keeping gradients low, and also in eliminating all unnecessary rise and fall of the gradeline. The most famous of his many roads was the Holyhead Road through the mountainous country of North Wales. In reconstructing this road he also relocated extensive parts of it to reduce the gradients—which were in many cases as steep as 10 or 16 percent—to a maximum of 3.33 percent. (*1*)

Later, Macneill measured road and grade resistances on the Holyhead Road with his dynamometer. He could then compute the ton-mile costs of haulage over any part of the road. By multiplying these costs by the number of tons which passed over the road in a year, he was able to compute the annual savings in user haulage costs attributable to the improvement. (*3*) Macneill's work, published in 1838, may be one of the earliest applications of what we know today as highway engineering economy.

Although the ideal maximum was around 3 percent, such low gradients were not practical in hilly and mountainous country because of the construction expense, and therefore most road authorities permitted steeper gradients under these conditions. In Prussia, for example, permissible gradients were 2.5 percent in level districts, 4 percent in hilly districts, and 5 percent in the mountains. In France, ruling grades depended on the political importance of the road rather than topography. National roads were limited to 3 percent gradient, departmental roads to 4 percent, and subordinate roads to 6 percent. In many States of the United States 5.0 and even 6.0 percent maximum gradients were permissible on main roads. (2)

In all countries engineers provided 0.5 percent to 1.5 percent minimum gradients to promote longitudinal drainage, but some authorities thought that level grades were satisfactory for fills.

---

[3] A road grade is the plane created by cutting the hills and filling the valleys. When the grade is not level, the rate at which it ascends or descends is the gradient of the slope; but frequently the term *grade* is used also for the rate of slope. Gradient is now almost universally expressed as units of rise per hundred units of horizontal distance, or percent.

Superior Tractive Ability of Motor Vehicles

Trucks and automobiles got along very comfortably on the relatively light grades of the wagon roads built in the United States during the *Good Roads Movement*. However they were mechanically capable of much better grade performance than the prevailing 5 to 6 percent maximums. As early as 1916, one could buy a 5-ton truck that could ascend a brick-paved hill of 13 percent gradient in low gear and, with special gearing, 27 percent was possible. (2) Automobiles of this period could ascend 6-percent hills of considerable length in high gear if they could get a running start and did not have to reduce speed for sharp curves. Released from the restrictions of animal power, designers no longer had to wind through the country seeking the easiest grades: they could go directly across country ignoring all but the greatest obstacles.

Charles Upham, one of the most influential highway engineers of the period, stated in 1920:

> More stress has been laid upon the alignment of roads during the past two or three years than ever before. It simply shows that highways are passing through the same stage that the railroads passed through when, after exhaustive studies from an economic standpoint, they spent considerable money for the straightening of their lines.
>
> In considering the alignment of commercial roads, or direct routes, it must always be remembered that a straight line is the shortest distance between two points, and from a commercial standpoint the shortest way is not only the most direct, but with other things equal, is the most economical, therefore, it seems to be practically conceded that ideally aligned commercial roads are those that are laid out in absolutely straight lines. Where there are costly influences entering the problem that make it impossible or impracticable to follow the straight line, then the alignment should approach the straight line, and become a compromise of line, grade, and cost of construction.
>
> In most States it is impracticable and almost impossible to hold a grade as low as 6 percent. . . . (4)

Upham's advice was widely followed by the engineers who executed the great road programs of the 1920's and 1930's in the United States. They shortened road distances in the aggregate by hundreds of miles and long *tangents* or straightaways became commonplace. To maintain these long tangents through rolling country they sometimes used gradients as steep as 9 percent, and in a summary of current practice made by the Bureau of Public Roads in 1929 it was stated:

> On main-line highways it is customary to adopt a maximum grade of 5 percent in gently rolling country and 7 percent in rough country, but it is no longer considered good practice to resort to sharp curvature in order to avoid grades somewhat steeper than 7 percent. If local conditions permit either a 7 percent grade with a sharp curve or a short 9 percent grade with a wider curve, the latter design is thought to be the better practice because it is safer for modern motor traffic. (5)

Grade Design for Early Motor Roads

Coincident with the widespread adoption of long-tangent location there arose two schools of thought as to how the vertical alinement or profile should be designed in rolling topography. Engineers of the *railroad* school preferred long easy grades connected by long flat vertical curves involving heavy cuts and fills, such as were the rule in railroad location then as now. On the other hand, engineers of the *rolling grade* or *humping* school preferred to follow the ground profile closely, using gradients up to 9 percent if necessary to avoid deep cuts and fills. (6)

Humping did save excavation—in some extreme cases as much as 20 percent—but it produced a *roller-coaster gradeline* with short sight distances between the humps and valleys. This, combined with the unlimited speed possible on tangents, made for a dangerous alinement, as well as a monotonous one.

Since the 1930's, the cost of earth-moving has been so greatly reduced by mechanization that earth work has become a relatively less important component of the total cost of road-building, and grade-rolling is much less pronounced. In fact, for heavy-traffic roads we have for all practical purposes returned to the *railroad gradeline*.

Railroad engineers have known for many years that track resistance increases on curves, especially sharp ones. To compensate for this added resistance they flattened the gradient a little on the sharper curves so that the train would not have to slow down too much when going upgrade around these curves.

Highway engineers of the 1920's, many of whom had been trained as railroad engineers, carried the idea of *grade compensation* over into highway engineering and by 1928, it was customary to compensate or reduce the gradient on curves of less than 500-feet radius. The amount of compensation was purely empirical. Grade compensation is less important today because trucks and automobiles are more powerful, and permissible grades and curvature are more moderate than they were 40 years ago. Nevertheless, it is still considered good design in mountainous areas to flatten the grade slightly on curves of less than about 800-feet radius.

Vertical Curves

In the days of animal power, roadbuilders paid little attention to vertical curves. After all, the angular difference between two 5 percent grades was only about 6° and this was hardly enough of a peak or valley to cause discomfort to a vehicle traveling only about 3 or 4 mph.

With the increasing road speeds that came with the automobile, road engineers began to worry about sight distances, especially over hill crests, and in 1919 one authority recommended that "vertical curves between grade tangents should be of large enough radius to provide for a proper line of sight between vehicles approaching each other from opposite sides of the hill." This radius should be, it was stated, not less than 50 feet in most cases. (6) With the high-silhouette cars of that day this rule gave about 300 feet sight distance over a summit between two 5 percent grades.

Another authority of the same period recommended parabolic vertical curves with lengths varying according to the algebraic difference between the intersecting grades. "Experience has proved that the following lengths will make satisfactory curves: 100 ft., 200 ft., 300 ft., for algebraic differences in grades between 1 and 3, 3 and 6, and more than 6 percent, respectively." (6)

In 1929 the American Association of State Highway Officials (AASHO), in one of its earliest standards, recommended "that horizontal and vertical curves be used which provide a sight distance of at least 500 feet." At this time, in U.S. practice, sight distance was measured from an assumed operator's eye level of 4.5 feet above the road surface to another point on the road ahead, also 4.5 feet above the surface.

In the early 1930's, the German engineers were designing their *Autobahnen* for 370 meters (1,215 feet) minimum stopping sight distance—more than double the AASHO 1929 minimum. Furthermore, they measured this sight distance from an assumed operator eye height of 3.9 feet to an obstacle on the road that was only 8 inches high—assumptions which required much longer summit vertical curves than the American practice described earlier. The very long sight distances used by the Germans resulted from using a very high design speed—180 km/h (112 mph)—in the kinetic energy formula for stopping sight distance. To provide such sight distances the German engineers used circular vertical curves with radii as long as 54,700 feet for summits and 16,000 feet for sags.[4] (7)

In 1939 when the AASHO Committee on Planning and Design Policies considered the problem of sight distance, all members agreed that the American rule for measuring sight distance was risky because it did not allow for small obstacles such as fallen rocks or small animals on the pavement. Some members thought that the driver should be able to see the surface of the pavement ahead for the full distance required to stop from the design speed. However, calculations showed that such a rule would require vertical curves so long that construction cost would be prohibitive. Eventually, the Committee adopted a modification of the German rule. They retained the 4.5-foot driver eye level but measured sight distance to an obstacle projecting 4 inches upward from the pavement surface.[5] The vertical curves required by this so-called dead cat rule were much longer than those needed by the old rule, but were still within economic limits. The new rule also resulted in a better balance between horizontal and vertical sight distances.

Agg's Theory of Grades

We have seen how the design speed concept provided engineers with a logical means of achieving consistent, *balanced design* for horizontal alinement, and also for vertical curvature. The designer had only to select a design speed, and the other dependent design elements—sight distance, horizontal radius, superelevation, length of spiral, length of vertical curve—were to a large extent decided for him. However, it was not nearly so easy to arrive at a logical maximum or limiting gradient to be used for a particular design speed.

As early as 1919, Thomas R. Agg, one of the modern founders of the discipline of highway engineering economy, proposed a method for solving location problems involving grades, based to a large extent on the already well-established railroad theory of grades. (*8*) Agg believed that grades should be designed to take into account the inherent characteristics of the motor vehicle—especially its motive power—then supplied with few exceptions by the throttle-governed, four-cycle internal combustion motor. This motor was most efficient when operating at or near full load at the speed for which it was designed. He analyzed the mechanical characteristics of several makes of automobiles and trucks, and then prepared tables showing the tractive effort that could be exerted by a composite average truck and a composite average automobile at various gear ratios. Then, using these values and assuming some loss of velocity on the hill, he was able to compute the maximum gradient that the vehicle could surmount at full power in high gear without dropping below a minimum acceptable velocity, which for trucks was 15 mph and for autos 25 mph.

---

[4] For two intersecting 5 percent grades these radii are approximately equivalent to simple parabolas 5,500 feet and 1,360 feet long, respectively.

[5] In 1965 AASHO changed this rule to provide for an operator eye level of 3.75 feet and an obstacle height of 6 inches.

Agg believed that the most economical descending grade was one that would "permit the vehicle to descend without the use of power or the brakes, and without attaining an unsafe speed." He assumed that an automobile would reach the top of a hill traveling 25 mph and then gather momentum under the pull of gravity until it was traveling 40 mph when it reached the foot of the hill. (Corresponding speeds for trucks would be 15 and 25 mph.) During its descent the vehicle would be urged forward by the pull of gravity but at the same time restrained by air resistance, rolling resistance, and the inertia of the vehicle's rotating parts.

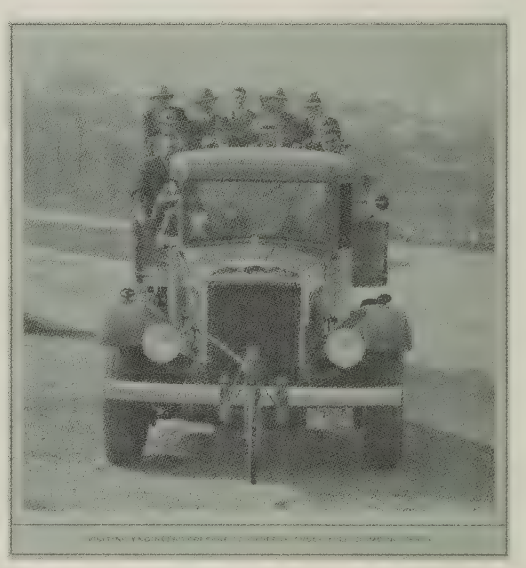
Agg found that *ideal* gradients—those that were most efficient and resulted in the least fuel consumption—were about 4 percent steeper for ascending grades than for descending grades, so the problem of economical grade design was to find average gradients that would yield the greatest overall economy. In a real situation he recommended that the designer lay a tentative gradeline and then, knowing the traffic count and percentage of trucks, calculate the average fuel consumption. He could then lay another, easier gradeline and recompute the fuel consumption. If the annual savings of fuel were equal to or greater than the annual construction cost of the grade reduction, the change could be deemed economical.

Although straightforward in principle, Agg's analysis was somewhat laborious in practice, and it is safe to say that it was not widely used in ordinary highway design. The economy of gradeline design continued to be judged more by the balancing of cut and fill volumes and savings in construction cost than by the economics of vehicle operation.

Measuring the Grade Ability of Trucks

In the late 1930's and early 1940's, studies of highway capacity by the Public Roads Administration (PRA) (the former Bureau of Public Roads) and the States opened a new approach to the design of highway grades. One of these studies, made in 1938, measured the hill-climbing ability of motor trucks. (9) This study was undertaken partly because of the PRA's desire to evaluate the traffic congestion caused by slow vehicles on the highway, and partly because of the desire of the vehicle manufacturers and truckers to head off restrictive legislation that would limit the weight of cargoes or impose high power requirements on trucks. (A widely advocated requirement of the period was that trucks be able to maintain 20 mph on a 4-percent grade.)

In the course of this study the researchers measured the maximum sustained speeds—the speeds after



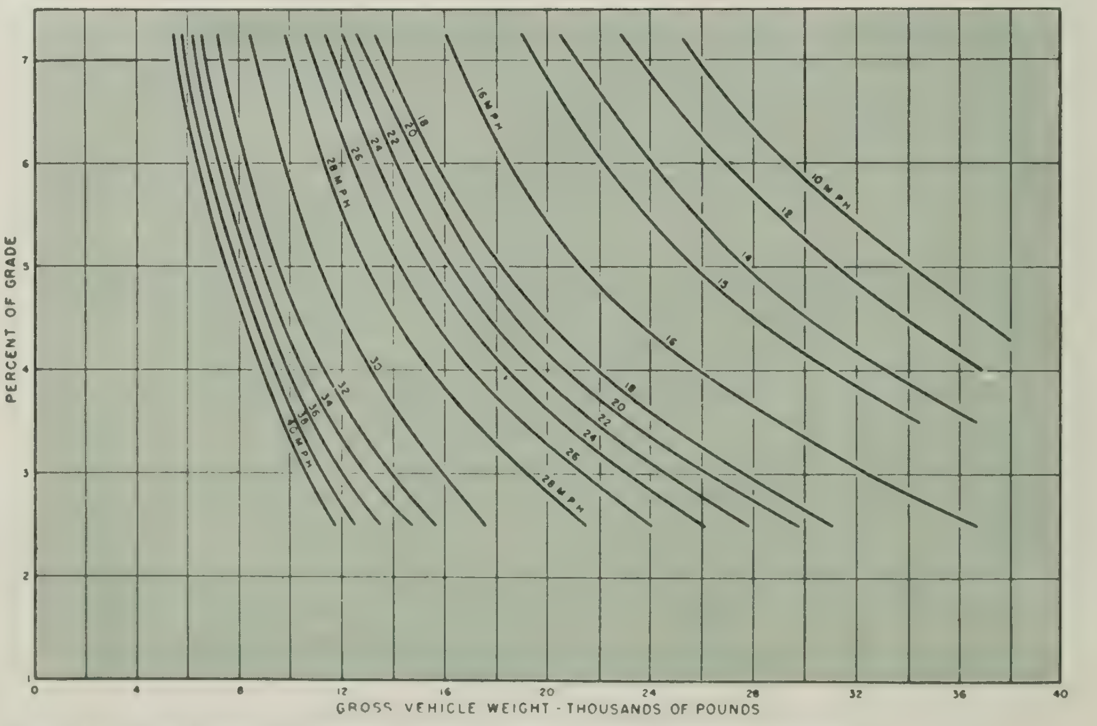


Figure 1.—Grade ability of light trucks and tractor trucks (without governor).

exhaustion of any initial momentum—that could be maintained on grades by 47 typical new and used trucks. The trucks were of various models from heavy to light and they were tested on actual grades of 3.2, 4.0, 4.5, 6.0, and 7.0 percent. The investigators placed known loads on each truck starting with the maximum weight that could be hauled in the lowest gear, and the truck's speed performance was measured on one of the grades with an extremely accurate bicycle wheel chronograph mounted on the front bumper. The load was then reduced by 1,000 pounds and the test run was repeated in the same gear. This procedure was repeated n successive decrements of 1,000 pounds until the observed road speed corresponded to the maximum engine speed recommended by the manufacturer. The test was then run over again in the next higher gear. The full range of tests was then performed on the other grades. Figure 1 shows the speed performance of light trucks as measured by these ests. Similar graphs were compiled or medium and heavy vehicles.

The most significant information that stands out in figure 1 is the small ncrease in speed that results from a reduction in gradient. Thus, for an average light tractor-truck weighing 24,000 pounds gross, a reduction in gradient from 6 percent to 5 percent would improve speed only 1.3 mph (from 14.0 mph to 15.3 mph). To ignificantly increase speed say to 23 mph, the gradient would have to be reduced to 3 percent. Looking at t another way, to maintain a speed of 23 mph on a 6 percent grade the ame truck could carry a gross load of only 14,000 pounds. The reduction would have to come out of the payload which originally was about 12,000 pounds, so there would be a net loss to the trucker of 83 percent.

Another way to increase speed is to increase engine power, but the researchers found that to obtain a road speed increase of 3 mph on a 6 percent grade would require an increase of 45 percent in the engine power of a typical 24,000-pound vehicle.

The investigators agreed that there was no single comprehensive solution to the problem and that any solution would probably involve some grade reduction coupled with a reduction in weight/power ratios for trucks. They stated, "Before a final conclusion can be reached, the reasonable minimum speed must be determined and the relative economics of the three basic methods [grade reduction, load reduction, power increase] and of their combinations must be determined." For the immediate future they thought the best policy was to widen roads at the points of most serious congestion, that is by adding climbing lanes, since an improvement in weight/power ratios would come only very gradually. (9)

The Effect of Momentum

The 1938 truck study specifically excluded the effects of momentum from consideration. However, under actual traffic conditions momentum is always present and it very materially increases the ability of vehicles to surmount grades. Realizing this, A. Taragin of the PRA in 1945 analyzed the data from the 1938 tests to determine the tractive effort exerted by the test vehicles for the various sustained speeds that were measured. *(10)* This tractive effort, added to the vehicle's kinetic energy or momentum, is expended in lifting the vehicle up the grade and in overcoming tractive resistance. Taragin was able to show, for example, that if a 40,000-pound vehicle approaches a 4 percent grade at 41 mph with the engine disengaged, it will coast 770 feet before its speed drops to 20 mph (fig. 2). If instead of coasting, the operator approaches the grade at a speed of 41 mph and applies the engine power, momentum plus tractive effort will take the vehicle

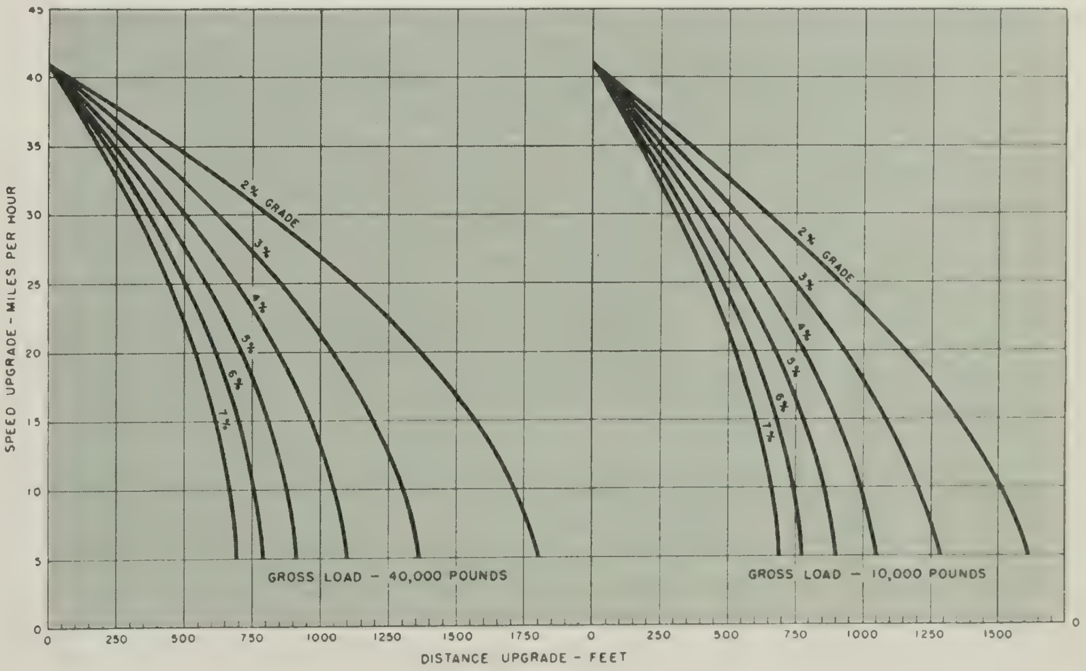


Figure 2.—Distance upgrade that the momentum alone will carry vehicles traveling at various speeds (engine disengaged).

1,500 feet up the grade before the speed drops to 20 mph (fig. 3). Only on grades that are longer than 2,500 feet would the vehicle have expended all of its momentum and be reduced to its *sustained speed* of 12.7 mph.

The PRA analysis showed that short grades do not seriously slow down trucks if the road conditions are such that they can get a running start and enter the grade at substantial speed. On longer grades the speed progressively drops until it reaches the maximum sustained speed or *crawl speed* of which the vehicle is capable. If the length of grade requiring operation at sustained speed is appreciable, satisfactory operation can only be achieved with auxiliary climbing lanes.

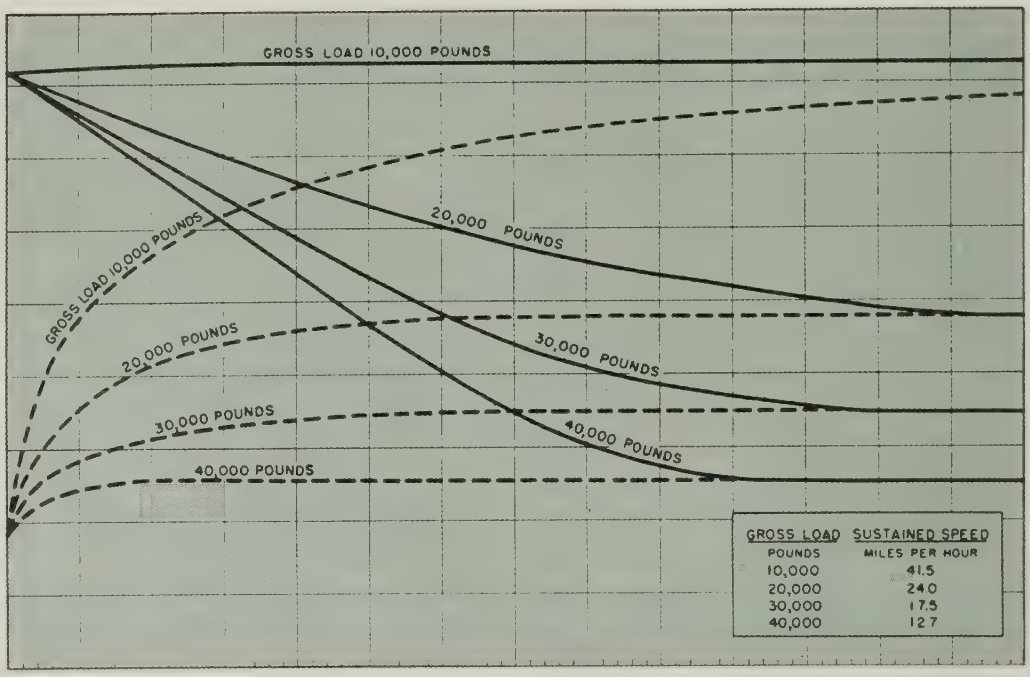


Figure 3.—Effect of gross load on the speed of medium motor vehicles on a 4.0 percent grade.

Arizona Grade Studies

The 1945 PRA study was a theoretical analysis based on the performance of 1938-model trucks. To update the BPR findings engineers of the Arizona Highway Department in 1949 observed the performance of 160 light, medium, and heavy trucks on various mountain grades, ranging from 2.0 percent to over 6 percent. The trucks were stopped several miles from the test grades and were weighed, and pertinent data as to horsepower and load were obtained from the driver. The truck was then allowed to proceed. Observers in a following car noted the truck's speed on arrival at the foot of the test grade and the distance at which the vehicle reached crawl speed. (*11*)

The observers found that the average speed of the trucks when they reached the foot of the grade was 47 mph, but many were clocked at speeds up to 65 mph. Thereafter, they lost speed at a rate which varied with the grade and also with the skill of the driver in knowing when to change gears. Typically, the loss of speed varied from 2 mph per thousand feet of grade on 2 percent grades to 33.5 mph per thousand feet of grade on 7 percent grades. Figure 4 is a composite of the speed-grade performance of heavy and medium trucks loaded to capacity or nearly so.

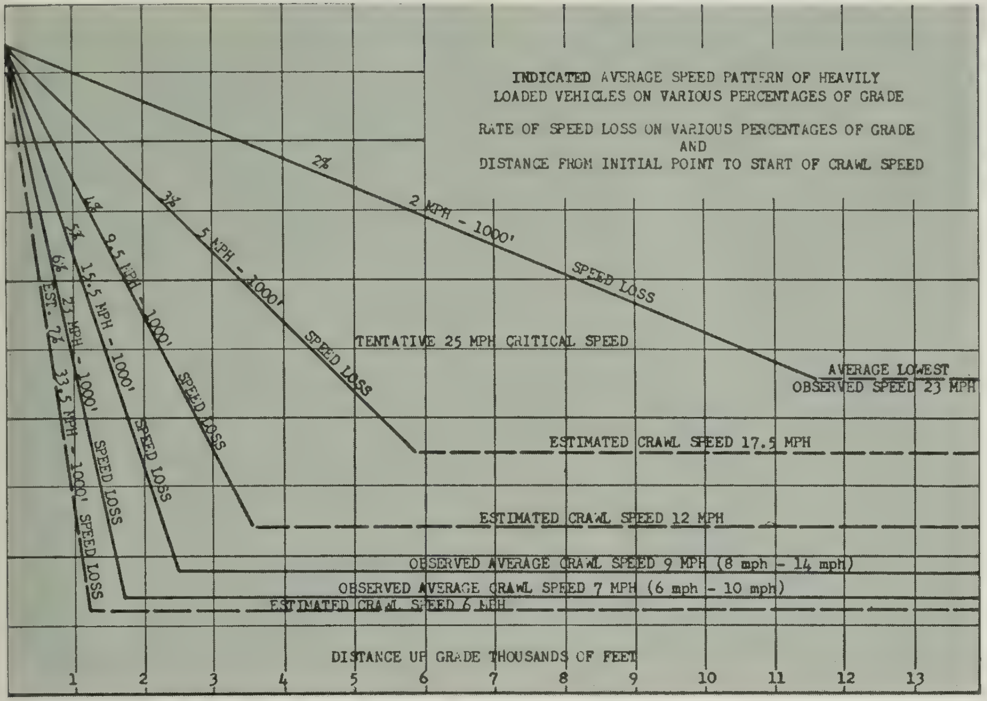
The Arizona engineers were concerned over the slow crawl speeds for the steeper grades not only because of congestion, but also for safety. They proposed a minimum *critical speed* of 25 mph on grades. If the hill was long enough to slow heavy vehicles down below that speed, they proposed to provide a climbing lane so that the slow vehicles could get out of the traffic stream and let the fast ones go by. The point at which the speed dropped to 25 mph would be the place to begin the climbing lane. Thus, in figure 4 if a 5 percent grade is longer than 1,500 feet, a climbing lane will be required upgrade from the 1,500-foot point.

The Texas Heavy Test Vehicle

In 1953, the Texas Highway Department made a series of road tests with a 29-ton tractor-semi-trailer test vehicle. The tests were made on various grades and the speeds attained during the test runs were automatically recorded by road detectors and graphic recorders. The average results of 118 test runs were plotted on speed-distance curves similar to figure 4 which the Texas engineers used to determine the beginning and ending of climbing lanes for a minimum critical speed of 30 mph. (*12*)

Determining Critical Speed

In both the Arizona and Texas procedures the important factor for deciding when to use climbing lanes was the *critical speed* below which traffic operation became intolerable. This speed was a matter of judgment —Arizona opting for 25 mph and Texas for 30 mph. In 1954, the AASHO



igure 4.—Speed patterns on various grades.

Committee on Planning and Design olicies studied the available research nformation and decided that a eduction of 15 mph below the verage running speed for level ections of the same highway would e "tolerable" and recommended hat this value be used for grade esign. *(13)* Applying this rule to verage running speeds measured in 1963 results in the following tolerable ninimum speeds (*14*):

Design speed (mph)	30	40	50	60	70	80
Average running speed at low volume (mph)	28	36	44	52	58	64
Tolerable minimum speed on grades (mph)	13	21	29	37	43	49

he truck tests resulted in rather eneral agreement among engineers hat grades should if possible be kept elow 3 percent for highways carrying large volumes of heavy trucks. However, such low grades are expensive to construct, even in fairly easy country, so when AASHO issued its design standards for primary highways in May 1941, it made no recommendations for maximum grades, simply acknowledging that "agreement has not been reached on maximum grade or length of sustained grade to be used for various combinations of terrain and traffic density. Grades long enough to be classed as 'sustained grades' should be less than the maximum grade used on that section of highway." (*15*)

Search for a Consensus on Grades

In 1941 President Roosevelt appointed a distinguished committee "to investigate the need for a limited system of national highways to improve the facilities now available for interregional transportation, and to advise the Federal Works Administrator as to the desirable character of such improvement." (*16*) The Secretary of this Interregional Highway Committee, H. S. Fairbank of the Public Roads Administration, assembled an outstanding technical staff in Washington, D.C., consisting of the traffic and design experts who had been in the forefront of highway traffic research during the preceding decade.

The Committee's report, which appeared in 1944, recommended a system of 33,920 miles of highways designed for high-speed travel:

> All rural sections of the system shall be designed at all points and in all respects for safe travel by passenger vehicles at a speed of not less than 75 miles per hour, and by trucks and tractor combinations at a speed of not less than 60 miles per hour in flat topography. In more difficult terrain the speed for which the highway is designed may be reduced; but in no case to less than 55 miles per hour for passenger vehicles and 35 miles for trucks and tractor combinations in mountainous topography. All rural sections shall provide a sufficient number of traffic lanes and other facilities so that at no time, except during infrequent peak hours, will it be necessary because of the interference of other vehicles to reduce the average running speed to less than 50 miles per hour. (*16*)

The recommended system was enacted into law in the Federal Aid Highway Act of 1944, but Congress left the selection of the system and its design standards to the "joint action of the State highway departments of each State and the adjoining States." The design standards for the Interstate System adopted by the American Association of State Highway Officials in 1945 fell considerably short of those recommended by the Interregional Highway Committee, the minimum permissible design speeds being only 60, 50, and 40 mph for flat, rolling, and mountainous topography, respectively. The AASHO recommendations for gradients were equally cautious: "The maximum gradients preferably shall not exceed 5 percent and in any case shall not exceed 6 percent. On short lengths only, gradients of 7 percent may be used." (*15*)

In 1954, AASHO's Committee on Planning and Design Policies observed that "Design values have been determined and agreed upon for many highway features but few conclusions have been reached on roadway grades in relation to design speed." The Committee went on to state, "In the States which utilize design speed control, nearly one-half specify maximum grades of 3 to 4 percent for a design speed of 70 mph, and only a few States use a maximum of 6 percent for this design speed. If the more important highways only are considered it appears that a maximum grade of 7 or 8 percent would be representative for 30 mph design speed." (*13*)

By 1956 the States had reached agreement on maximum gradients for the Interstate System, and the AASHO standards approved that year stated:

> For design speeds of 70, 60, and 50 miles per hour, gradients generally shall be not steeper than 3, 4, and 5 percent, respectively. Gradients 2 percent steeper may be provided in rugged terrain. (*17*)

However, not until 1961 did the States reach a consensus on what maximum gradients to use for highways other than freeways. AASHO standards adopted December 27, 1961, recommended the grades shown in table 1. Short grades less than 500 feet long and one-way down grades may be 1 percent steeper. For low volume rural roads, grades may be made 2 percent steeper.

Table 1.—Maximum grades in percent (*18*)

Topography	Design speed, mph				
	30	40	50	60	70
Flat	6	5	4	3	3
Rolling	7	6	5	4	4
Mountainous	9	8	7	6	—

The design speed concept for geometric design became AASHO policy in September 1938, yet 23 years elapsed before there was sufficient agreement among the States for AASHO to feel free to bring out a national policy on grades. This illustrates an important aspect of highway policy in the United States: Design practice generally evolves slowly over a long period, and crystallizes into formal *standards* only after a strong consensus has developed among informed engineers and administrators. We will examine this evolutionary development of standards in Part 8.

REFERENCES

(*1*) W. M. Gillespie, "A Manual of the Principles and Practice of Road Making," 10th ed., *A. S. Barnes,* New York, 1871, pp. 39, 42, 61, 62, 64.

(*2*) Wilson G. Harger and Edmund A. Bonney, "Handbook for Highway Engineers," 3d ed., *McGraw-Hill,* New York, 1919, pp. 11, 12, 15, 16, 18, 23.

(*3*) Albert C. Rose, "Public Roads of the Past —3500 B.C. to 1800 A.D.," *American Association of State Highway Officials,* Washington, D.C., 1952, p. 60.

(*4*) Charles M. Upham, "The Alignment, Grade, Width, and Thickness in Design of Road Surfaces," *Public Roads,* vol. 2, Nos. 21–22, January–February 1920, pp. 25–26.

(*5*) A. G. Bruce, "The Effect of Increased Speed of Vehicles on the Design of Highways," *Public Roads,* vol. 10, No. 1, March 1929, pp. 15, 16.

(*6*) A. H. Blanchard, ed., "American Highway Engineer's Handbook," 1st ed., *John Wiley,* New York, 1919, pp. 157, 304.

(*7*) I. Gutmann, "Engineering Sets High Mark on German Superhighways," *Engineering News-Record,* Aug. 27, 1936, p. 292.

(*8*) Thomas R. Agg, "Construction of Roads and Pavements," 3d ed., *McGraw-Hill,* New York, 1924, pp. 81–87.

(*9*) Carl A. Saal, "Hill Climbing Ability of Motor Trucks," *Public Roads,* vol. 23, No. 3, May 1942, pp. 33–54.

(*10*) A. Taragin, "Effect of Length of Grade on Speed of Motor Vehicles," Proceedings of the 25th Annual Meeting, vol. 25, *Highway Research Board,* Washington, D.C., 1945, pp. 342–353.

(*11*) W. E. Willey, "Survey of Uphill Speeds of Trucks on Mountain Grades," Proceedings of the 29th Annual Meeting, vol. 29, *Highway Research Board,* Washington, D.C., 1949, pp. 304–310.

(*12*) T. S. Huff and F. H. Scrivner, "Simplified Climbing—Lane Design Theory and Road-Test Results," Bulletin No. 104, Vehicle Climbing Lanes, *Highway Research Board,* Washington, D.C., 1955, pp. 1–11.

(*13*) "A Policy on Geometric Design of Rural Highways," *American Association of State Highway Officials,* Washington, D.C., 1954, pp. 165, 167, 169.

(*14*) "A Policy on Geometric Design of Rural Highways—1965," *American Association of State Highway Officials,* Washington, D.C., 1965, pp. 97, 155, 167.

(*15*) "A Policy on Design Standards, Policies on Geometric Highway Design," *American Association of State Highway Officials,* Washington, D.C., 1950, pp. 2, 3, 7.

(*16*) "Interregional Highways—A Report of the National Interregional Highway Committee," House Document No. 379, 78th Congress, 2d Session, *U.S. Government Printing Office,* 1944, pp. III, 94.

(*17*) "Geometric Design Standards for the National System of Interstate and Defense Highways," Adopted July 12, 1956, *American Association of State Highway Officials,* Washington, D.C., 1956, p. 3.

(*18*) "Geometric Design Standards for Highways Other Than Freeways," Adopted Dec. 27, 1961, *American Association of State Highway Officials,* Washington, D.C., 1965, p. 7.

Our Authors

Truman M. Mast is a research psychologist in the Traffic Systems Division, Office of Research, Federal Highway Administration. He is responsible for the direction of human factors research on Highway Information Systems and has authored technical reports on diagrammatic and real-time motorist information displays. Prior to joining the FHWA Dr. Mast was Assistant Professor of Psychology at Montana State University.

James A. Ballas is a research psychologist in the Traffic Systems Division, Office of Research, Federal Highway Administration. His present activities include research on route diversion signing and computer models of driver behavior. Before joining FHWA in 1974, he was a research associate at Montana State University and developed a model of student pedestrian traffic. He also served as a data analyst on an interdisciplinary team engaged in environmental impact research.

Joseph I. Peters is a research psychologist in the Traffic Systems Division, Office of Research, Federal Highway Administration. As a graduate student at the Catholic University of America, he participated in research on human factor implications for real-time signing and drivers' understanding of road markings. Since joining FHWA in 1975, he has been involved with instrumented vehicle research on radio message and real-time signing techniques for route diversion.

Joseph C. Leifer is an electronic research engineer in the Engineering Services Division, Office of Development, Federal Highway Administration. Mr. Leifer has been responsible for the design and development of electronic instrumentation and data handling systems for over 25 years in a career that includes employment at Melpar, Inc., AMF, and the U.S. Naval Research Laboratory.

Anthony J. Knepp, currently principal investigator for the project on Evaluation of Flood Risk Factors in the Design of Highway Crossings, is an associate engineer with Water Resources Engineers, Inc., of Springfield, Va. He has been involved in numerical modeling of hydraulic problems with particular emphasis on storm water systems.

Ming T. Tseng is presently a hydraulics engineer for the U.S. Army Corps of Engineers. He was previously the principal investigator and responsible for the early direction of the project on Evaluation of Flood Risk Factors in the Design of Highway Crossings. Dr. Tseng is involved in design and review of flood control, navigation, hydropower, and water quality management projects. He also provides technical assistance to Corps of Engineers district offices on mathematical modeling of hydrologic and hydraulic problems.

J. Sterling Jones, the contract manager for the project on Evaluation of Flood Risk Factors in the Design of Highway Crossings, is a research engineer assigned to the Environmental Design and Control Division, Office of Research, Federal Highway Administration. He joined FHWA in 1971 and is involved in research of energy dissipators, scour around piers, and bridge backwater problems.

Samuel C. Tignor is a highway research engineer in the Traffic Systems Division, Office of Research, Federal Highway Administration. He is project manager for FCP Project 1C "Analysis and Remedies of Freeway Traffic Disturbances," and also manages research dealing with merging and freeway control systems. Dr. Tignor is a 1961 graduate of the FHWA Highway Engineering Training Program.

Implementation/User Items "how-to-do-it"

The following are brief descriptions of selected items which have been recently completed by State and Federal highway units in cooperation with the Implementation Division, Offices of Research and Development, Federal Highway Administration (FHWA). Some items by others are included when they have a special interest to highway agencies. These items will be available from the Implementation Division unless otherwise indicated. Those placed in the National Technical Information Service (NTIS) will be announced in this department after an NTIS accession number is assigned.

U.S. Department of Transportation
Federal Highway Administration
Office of Development
Implementation Division, HDV–20
Washington, D.C. 20590

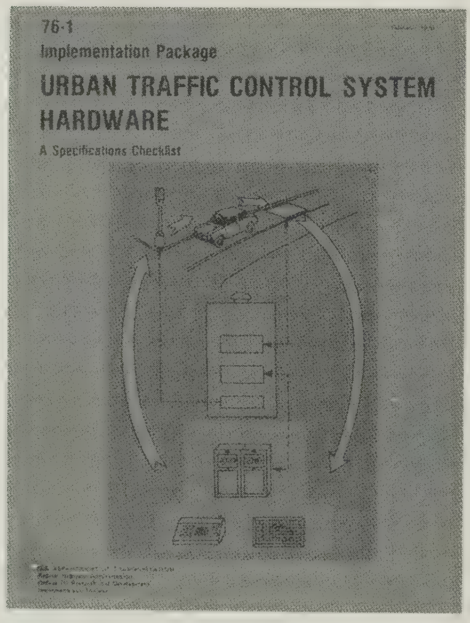
War on Wet Weather Accidents

by Texas State Department of Highways and Public Transportation

This 16 mm color film was produced by the Texas Transportation Institute (TTI) for the Texas State Department of Highways and Public Transportation. It is recommended for viewing by general audiences interested in skid resistance, tire hydroplaning, and highway safety since it offers advice derived from recent research on how to drive more safely on wet pavements.

It should be noted that TTI's recommendation in the film for using greater than manufacturers' specified tire pressures to reduce the probability for hydroplaning may have other adverse effects. In addition, two nonstandard signs warning motorists of slippery conditions are shown. These are under evaluation and their appearance in the film does not imply a recommendation for their use.

The film is available from the Implementation Division.



76-1
Implementation Package
URBAN TRAFFIC CONTROL SYSTEM HARDWARE
A Specifications Checklist

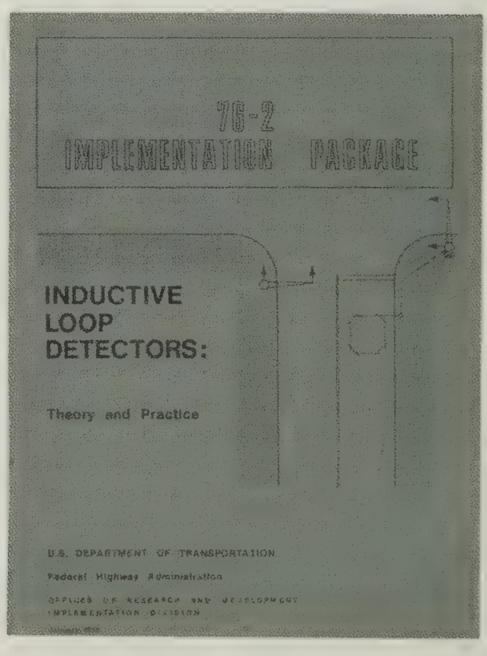
Urban Traffic Control System Hardware: A Specifications Checklist, Implementation Package 76–1

by FHWA Implementation Division

This manual consists of a compilation of the Urban Traffic Control System/Bus Priority System (UTCS/BPS) specification requirements which have been generalized and condensed into a checklist format.

The format of this manual provides a rapid means of checking equipment specifications which have been prepared, or are in the process of being prepared, for a similar traffic system. Each of the condensed specifications is a complete unit, and includes the original UTCS/BPS requirements necessary to insure adequate definition, performance, and quality of the equipment procured. The checklist specifications include a brief discussion, in the introduction, of the background, theory, and application of the equipment in computer-controlled traffic systems. The introductions are intended to provide some insight as to the reason for including the specification items in the checklist.

The manual is available from the Implementation Division.



76-2
IMPLEMENTATION PACKAGE
INDUCTIVE LOOP DETECTORS:
Theory and Practice
U.S. DEPARTMENT OF TRANSPORTATION
Federal Highway Administration
OFFICES OF RESEARCH AND DEVELOPMENT
IMPLEMENTATION DIVISION

Inductive Loop Detectors: Theory and Practice, Implementation Package 76–2

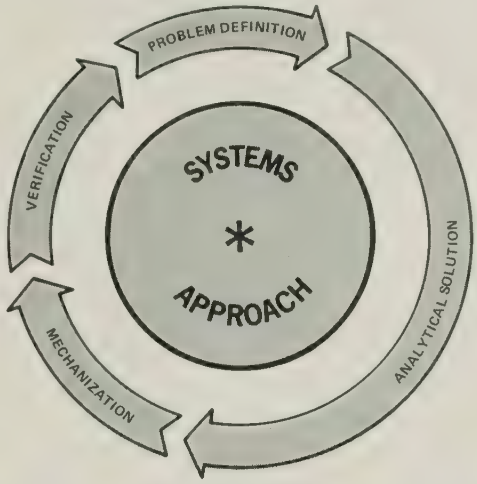
by FHWA Implementation Division

The need for an easily installed and relatively inexpensive system to provide passage and/or presence detection for traffic control purposes

has led to substantial use of an inductive loop system. In the past, a lack of standardized performance criteria has hampered the design, installation, and maintenance of loop detector systems and resulted in a considerable amount of experimentation during the installation phase.

This report provides a user's manual for design application and performance testing of inductive loop detector systems developed by the Department of Traffic, Los Angeles, Calif. It is based on a study of many of their approximately 3,000 loop detector field installations. The purpose of the study was to determine the causes of failure or intermittent operations and to develop aids for the design, test, and maintenance of these systems. Basic theory of loop detector operation is presented along with a discussion of loop size and shape. Installation procedures used in the Urban Traffic Control System (UTCS) in Washington, D.C., are described and discussions of practical ways to deal with the installation of loops across pavement joints are also included. A detector trouble-shooting procedure, with detailed instructions and data recording forms, is included in a form suitable for use by technicians.

The report is available from the Implementation Division.



Traffic Control Systems Handbook: Executive Summary, Implementation Package 76–3

by FHWA Implementation Division

This summary briefly outlines the contents of a Traffic Control Systems Handbook that has been developed by the Federal Highway Administration. The introduction presents the vital concern for implementing effective traffic control systems and identifies the somewhat confusing situation relative to the wide variety of traffic control technology and equipment. The summary includes a description of the handbook's scope and objectives as well as its presentation concept. The contents of the handbook are discussed in relation to each of the five phases of Traffic Control Systems Engineering: traffic control studies, synthesis, analysis, design and implementation, and management.

The summary is available from the Implementation Division.

Introduction to Concrete Polymer Materials, Report No. FHWA–RD–75–507

by Brookhaven National Laboratory for FHWA Implementation Division

Introduction to Concrete Polymer Materials, Supplement No. 1, Report No. FHWA–RD–75–527

by U.S. Bureau of Reclamation for FHWA Implementation Division

Concrete polymer composites are new materials showing promise in helping to alleviate some of the problems associated with concrete deterioration. The purpose of these texts is to provide highway personnel with a working knowledge of concrete polymer development and application.

Introduction to Concrete Polymer Materials presents basic information on polymer chemistry as applied to concrete polymer materials, the fundamental characteristics and properties of the materials, safety precautions, and a general discussion of potential applications.

Introduction to Concrete Polymer Materials, Supplement No. 1, includes discussions on the structural properties of polymer impregnated concrete and its application in prestressed bridge deck panels, polymer impregnation as a bridge deck sealant, polymer concrete, polymer shotcrete, and penetrating protective coatings.

Both volumes are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Introduction to Concrete Polymer Materials—Stock No. PB 241691; Introduction to Concrete Polymer Materials, Supplement No. 1—Stock No. PB 248227).

Calendar Year 1975 Accomplishment Report of the Implementation Division, Office of Development

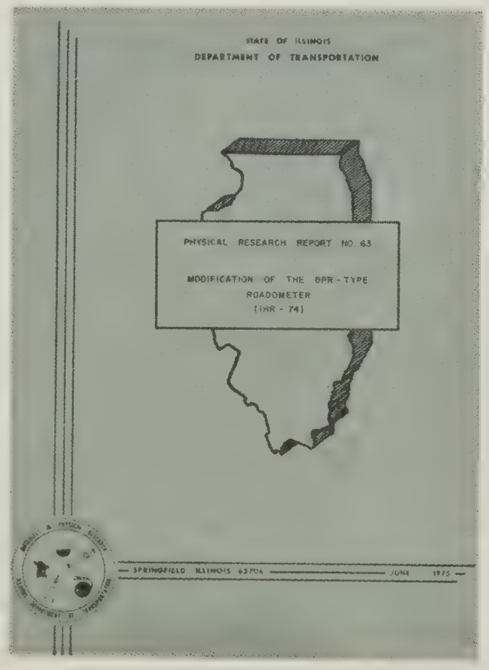
by FHWA Implementation Division

In this report, the two groups in the Implementation Division of the Office of Development, Federal Highway Administration, present a description of their activities for 1975.

The work of the Engineering, Location, and Design Group is discussed under seven program areas: (1) roadside safety, (2) traffic engineering, (3) highway design, (4) hydraulics and hydrology, (5) bridge and culvert design, (6) pedestrian safety, and (7) environmental. More than 60 projects are covered in this section of the report.

The Construction, Materials, and Methods Group is responsible for 10 program areas: skid, delineation, rapid tests, pavement, waste and substitute materials, polymers, tunnels, soils and foundations, structures, and maintenance. A total of 70 ongoing projects are discussed.

The report is available from the Implementation Division.



STATE OF ILLINOIS
DEPARTMENT OF TRANSPORTATION

PHYSICAL RESEARCH REPORT NO. 63

MODIFICATION OF THE BPR-TYPE
ROADOMETER
(IHR - 74)

SPRINGFIELD ILLINOIS 62706 JUNE 1975

Modification of the BPR-Type Roadometer

by the Illinois Department of Transportation and FHWA Implementation Division

This report describes a modification of the BPR roadometer that increases its utility in the measurement of road smoothness (or roughness). The following have been limitations of the roadometer: its inability to give reliable results on short test sections—less than ¼ to ½ mile (0.4 to 0.8 km); its operating speed of 20 mph (32 km/h); and the vertical motion resolution of 1 in (25.4 mm). Modifications made in the horizontal distance and vertical displacement sensing devices have improved the capabilities of this device for measuring pavement sections as short as 100 ft (30 m) and have increased the operating speed. Good results have been reported in the measurement of vertical displacement on 100-ft (30 m) sections with a displacement resolution of 0.01 in (0.25 mm). The measurement of distance increments has been reduced from approximately 7 ft (2 m) to 1 in (25.4 mm). Test results also show that the modified system can be operated at speeds up to 60 mph (97 km/h). The addition of an electronic system allows data to be recorded on printed paper tape. The system can also be adapted for magnetic tape data recording.

The report is available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Stock No. PB 248627).

New Research in Progress

The following items identify new research studies that have been reported by FHWA's Office of Research and Development. Space limitation precludes publishing a complete list. These studies are sponsored in whole or in part with Federal highway funds. For further details, please contact the following: Staff and Contract Research—Editor; Highway Planning and Research (HP&R Research)—Performing State Highway Department; National Cooperative Highway Research Program (NCHRP)—Program Director, National Cooperative Highway Research Program, Transportation Research Board, 2101 Constitution Avenue, NW., Washington, D.C. 20418.

FCP Category 1—Improved Highway Design and Operation for Safety

FCP Project 1A: Traffic Engineering Improvements for Safety

Title: Safety Aspects of Vehicle Parking. (FCP No. 31A1613)
Objective: Determine safety and operational characteristics of onstreet parking alternatives; collect and form a data base to compare these various alternatives; and prepare a manual to be used by local officials to determine site specific parking arrangements.
Performing Organization: University of Tennessee, Knoxville, Tenn. 37916
Expected Completion Date: November 1977
Estimated Cost: $140,000 (FHWA Administrative Contract)

FCP Project 1G: Safer Traffic Guardrails and Bridge Railings

Title: Assessment of Probability of Injury in the Analysis and Testing of Barrier Concepts. (FCP No. 31G1133)
Objective: Provide the details and tools by which advanced methods in the area of occupant modeling and injury assessment can be incorporated into the analysis and testing methods used for highway roadside furniture safety evaluations.
Performing Organization: Ensco, Inc., Springfield, Va. 22151
Expected Completion Date: June 1977
Estimated Cost: $129,000 (FHWA Administrative Contract)

Title: Vehicular Crash Tests on Continuous Concrete Median Barriers Without Footings. (FCP No. 41G1212)
Objective: Conduct vehicle crash test on 50 CMB without footings and 50-C-CMB without footings for the purpose of judging the strength and stability of these barrier designs.
Performing Organization: California Department of Transportation, Sacramento, Calif. 95814
Expected Completion Date: March 1979
Estimated Cost: $73,000 (HP&R)

FCP Project 1J: Improved Geometric Design

Title: Operation Problems on Cloverleaf Interchanges. (FCP No. 31J2122)
Objective: Determine the safety and operational problems associated with weave areas, loop ramps, and terminal areas of full cloverleaf interchanges. Identify potential countermeasures to alleviate these problems.
Performing Organization: Institute for Research, State College, Pa. 16801
Expected Completion Date: June 1977
Estimated Cost: $89,000 (FHWA Administrative Contract)

FCP Project 1K: Accident Research and Factors for Economic Analysis

Title: Development of Safer Utility Poles. (FCP No. 31K6034)
Objective: Phase I—develop retrofit solutions to significantly improve performance of existing utility poles with regard to structural dynamics. Phase II—evaluate new concepts for use in new construction.
Performing Organization: Southwest Research Institute, San Antonio, Tex. 78284
Expected Completion Date: March 1978
Estimated Cost: $212,000 (FHWA Administrative Contract)

FCP Category 2—Reduction of Traffic Congestion, and Improved Operational Efficiency

FCP Project 2J: Practicality of Automated Highways

Title: Practicality of Automated Highway Systems. (FCP No. 32J1011)
Objective: Evaluate generic concept designs and conduct research of those concepts to determine the technical, human factors, social, economic, legal, and environmental feasibilities of the automated highway systems.
Performing Organization: Calspan Corporation, Buffalo, N.Y. 14221
Expected Completion Date: October 1977
Estimated Cost: $272,000 (FHWA Administrative Contract)

FCP Project 2K: Metropolitan Intermodal Traffic Management

Title: Optimization Techniques for Urban Transportation Systems. (FCP No. 32K1023)
Objective: Produce a computer program capable of optimizing signals and lane assignments in a corridor. Simplifying assumptions will be made to see if the concept is feasible.
Performing Organization: Electronic Systems Laboratory, Massachusetts Institute of Technology, Cambridge, Mass. 02139
Expected Completion Date: March 1977
Estimated Cost: $75,000 (FHWA Administrative Contract)

FCP Category 3—Environmental Considerations in Highway Design, Location, Construction, and Operation

FCP Project 3F: Pollution Reduction and Visual Enhancement

Title: Implementation and Extension of Fine Grasses for Roadsides. (FCP No. 43F1922)
Objective: Demonstrate comparison stands of fine grass mixtures developed under project 7726 with the present "A" mix. Synthesize a new spreading fescue variety from improved stock of roadside origin.
Performing Organization: Rutgers University, New Brunswick, N.J. 08903
Funding Agency: New Jersey Department of Transportation
Expected Completion Date: June 1979
Estimated Cost: $146,000 (HP&R)

Title: Air Monitoring Quality Assurance Program. (FCP No. 43F3273)
Objective: Develop a quality assurance program involving the standardization of laboratory and field audit and calibration procedures, certification criteria, and statistical quality assurance procedures.
Performing Organization: California Department of Transportation, Sacramento, Calif. 95807
Expected Completion Date: June 1979
Estimated Cost: $212,000 (HP&R)

FCP Category 4—Improved Materials Utilization and Durability

FCP Project 4B: Eliminate Premature Deterioration of Portland Cement Concrete

Title: Develop and Evaluate Alternate Cathodic Protection Systems. (FCP No. 44B1542)
Objective: Provide alternate cost-effective cathodic protection systems through the development and evaluation of alternate materials and forms of anodes and overlays, initially evaluate the new concepts in the laboratory, construct field installations, and evaluate using those systems which perform well in the laboratory.
Performing Organization: California Department of Transportation, Sacramento, Calif. 95814
Expected Completion Date: June 1979
Estimated Cost: $605,000 (HP&R)

Title: Feasibility Evaluation of the Implementation of Concrete Polymers for Bridge Deck Applications. (FCP No. 44B2262)
Objective: Provide the Oklahoma Department of Highways with specifications and information necessary to utilize polymers with concrete in bridge deck repair and rehabilitation. Work includes a literature survey, laboratory evaluation of materials and processes for production of concrete with polymers, and finally, application of information developed to uses in the Oklahoma highway system.
Performing Organization: University of Oklahoma, Norman, Okla. 73069
Funding Agency: Oklahoma Department of Highways
Expected Completion Date: March 1979
Estimated Cost: $80,000 (HP&R)

FCP Project 4D: Remedial Treatment of Soil Materials for Earth Structures and Foundations

Title: Full Depth Testing of Frost Susceptible Soils. (FCP No. 44D4072)
Objective: Examine various soil types under similar environmental and natural freezing conditions in order to determine their relative frost susceptibility.
Performing Organization: Massachusetts Department of Public Works, Boston, Mass. 02114
Expected Completion Date: June 1980
Estimated Cost: $88,000 (HP&R)

FCP Category 5—Improved Design to Reduce Costs, Extend Life Expectancy, and Improve Structural Safety

FCP Project 5B: Tunneling Technology for Future Highways

Title: Improved Earth Reinforcement Techniques for Use in Cut-and-Cove Tunneling. (FCP No. 35B1041)
Objective: Develop an improved earth reinforcement technique for us

☆ U.S. Government Printing Office: 1976—621-805/

in stabilizing earth masses in place through comprehensive evaluation of the fondedile system "reticulated pali radice," and develop an improved reinforcement technique based on using a group of piles to stabilize a soil mass.
Performing Organization: Corps of Engineers, Waterways Experiment Station, Vicksburg, Miss. 39180
Expected Completion Date: October 1979
Estimated Cost: $596,000 (FHWA Administrative Contract)

FCP Project 5D: Structural Rehabilitation of Pavement Systems

Title: Overlays for Plain Concrete Pavement. (FCP No. 45D2454)
Objective: Determine which of the overlay designs (four different sections of concrete, 12 sections of asphalt) will give adequate performance considering cost and pavement ife.
Performing Organization: Georgia Department of Transportation, Atlanta, Ga. 30334
Expected Completion Date: May 1981
Estimated Cost: $88,000 (HP&R)

Title: Performance of an Experimental Contraction Jointed Pavement Design. FCP No. 45D2464)
Objective: Evaluate the contraction oint design, determine capability of he end anchor systems used, detect any distress condition in its early tages, and recommend appropriate naintenance.
Performing Organization: New Jersey Department of Transportation, Trenton, N.J. 08625
xpected Completion Date: April 986
Estimated Cost: $70,000 (HP&R)

FCP Project 5E: Premium Pavements for "Zero Maintenance"

Title: Prestressed Concrete Pavement. (FCP No. 45E3024)
Objective: Instrument and accumulate research data from FHWA Demonstration Project No. 17 for prestressed concrete pavement.
Performing Organization: Mississippi State Highway Department, Jackson, Miss. 39205
Expected Completion Date: April 1983
Estimated Cost: $149,000 (HP&R)

FCP Project 5F: Structural Integrity and Life Expectancy of Bridges

Title: Detection of Flaws in Reinforcing Steel in Prestressed Concrete Bridge Members. (FCP No. 35F1042)
Objective: Review of the state of the art for nondestructive inspection to select a method(s) for detecting flaws in the reinforcement of prestressed concrete highway bridges and to develop and deliver the inspection equipment.
Performing Organization: Southwest Research Institute, San Antonio, Tex. 78284
Expected Completion Date: October 1977
Estimated Cost: $101,000 (FHWA Administrative Contract)

Title: Acoustic Emission Methods for Flaw Detection in Steel in Highway Bridges. (FCP No. 35F1062)
Objective: Fabricate and deliver a workable acoustic emission self monitoring unit with source isolation capability.
Performing Organization: Battelle Northwest, Richland, Wash. 99352
Expected Completion Date: March 1977
Estimated Cost: $70,000 (FHWA Administrative Contract)

Non-FCP Category 0—Other New Studies

Title: Water Base Coatings for Protection of Steel Structures. (FCP No. 40M3372)
Objective: Formulate and evaluate various types of water base coatings for use over zinc primer; formulate and evaluate complete water base primer and topcoat systems that would be equal to or better than present alkyo type maintenance paint.
Performing Organization: California Department of Transportation, Sacramento, Calif. 95807

Expected Completion Date: April 1979
Estimated Cost: $78,000 (HP&R)

Title: Prestressed Zero Maintenance Pavements (Evaluations, Recommendations, and Documentation)—Study I. (FCP No. 30S4622)
Objective: Update, evaluate, recommend, and document technology for prestressed concrete pavements.
Performing Organization: Portland Cement Association, Skokie, Ill. 60076
Expected Completion Date: January 1978
Estimated Cost: $356,000 (FHWA Administrative Contract)

Notice

Beginning with this issue the department "Highway Research and Development Reports Available from the National Technical Information Service" will no longer be published in *Public Roads*. This department will be replaced in the December 1976 issue by a new department, "Recent Research Reports You Should Know About."

United States
Government Printing Office
Superintendent of Documents
WASHINGTON, D.C. 20402

Official Business

PENALTY FOR PRIVATE USE, $300
POSTAGE AND FEES PAID
FEDERAL HIGHWAY ADMINISTRATION
DOT 512

U.S.MAIL

FIRST CLASS

publ
road

A JOURNAL OF HIGHWAY RESEARCH AND DEVELOP